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Bulletin *of the State University and School of Mines*
of North Dakota

VOL. 1, NO. 1 *JANUARY 15, 1903*

SECOND BIENNIAL REPORT

OF THE

State Geological Survey of North Dakota

SECOND EDITION

Ordered by resolution of Legislative Assembly

FRANK A. WILDER, Ph. D.
State Geologist

OCTOBER 1ST 1889

BISMARCK, 1903

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GEOLOGICAL SURVEY

OF

NORTH DAKOTA

SECOND EDITION

OF

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October 1st 1889

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1902

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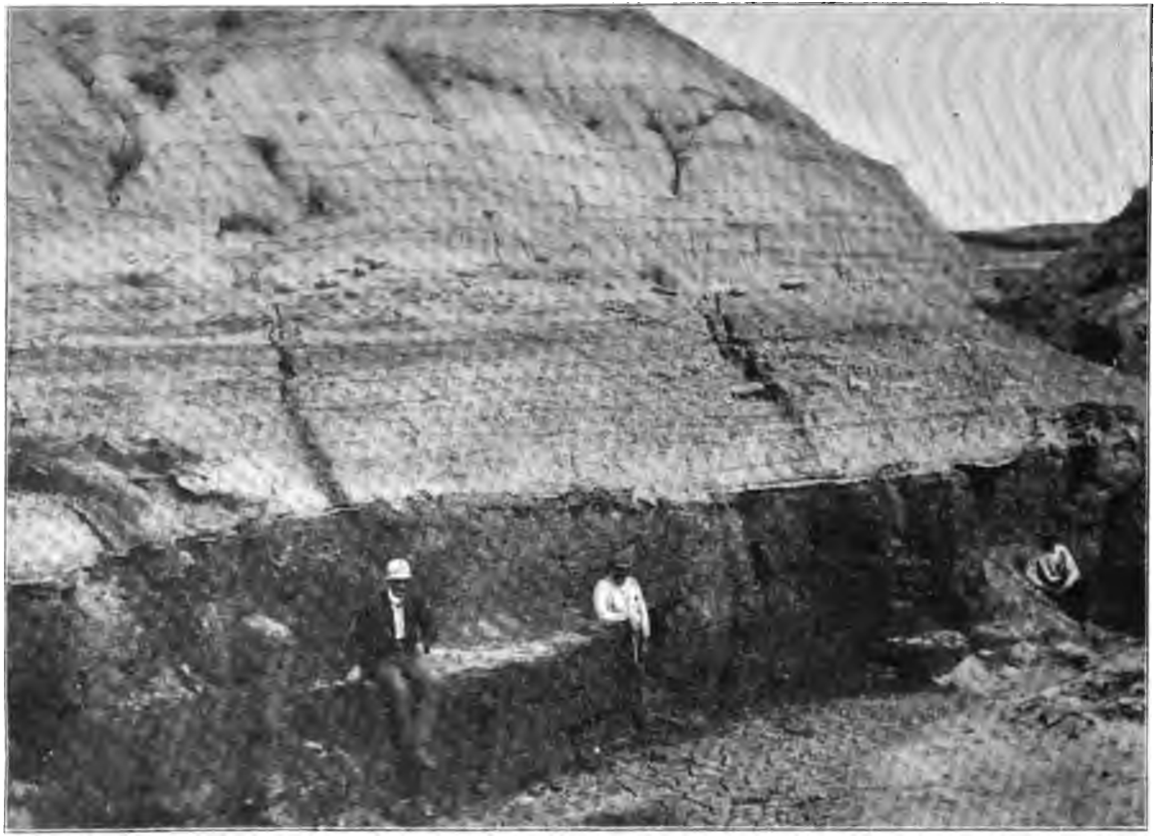

A Twelve-Foot Lignite Seam Near Williston, the Lower Portion Not Exposed, Showing the Laramie Clays With Rows of Concretions in the Bare Slopes Above.

ADMINISTRATIVE REPORTS

ADMINISTRATIVE REPORTS

University of North Dakota,
Grand Forks, Nov. 19, 1902.

To the Trustees of the University of North Dakota:

Gentlemen: With the publication of the forthcoming volume of the Geological Survey of North Dakota my connection with the Survey as geologist ceases. The work of the Survey has been growing so rapidly during the past two or three years that it has been impossible for me to attend to it longer in addition to my other duties as director of the department of chemistry and the School of Mines. The change is one which I have strongly urged for years upon your honorable body. It is with pleasure, therefore, that I now turn over this work to Dr. Frank A. Wilder, who was elected to the position of State Geologist in June last.

The work which I have done in organizing the Survey and in publishing investigations thus far made has been of a pioneer nature and purely a labor of love. For several years after the organization of the Survey no funds were appropriated. During this time the work was carried on in the summer vacation months, and the expense, amounting to two or three thousands of dollars, I have freely donated to the state for the good of the cause.

Under such conditions it has been possible to do nothing more than the preliminary work, which has resulted in several bulletins and the first report of the Survey published two years ago. At the present time a small amount is available for the expenses connected with this work. This, in addition to the appointment of a man to give his time to the work, will make it possible to build up a systematic and extremely valuable survey in North Dakota. The available funds are, however, entirely inadequate for the amount of work which should be undertaken, and it is earnestly hoped that a much more liberal provision will be made at once for the Geological Survey. In a new state like ours such work is of the utmost economic importance. There are vast resources untouched and perhaps unknown, which must be investigated and brought to the attention of our citizens and those elsewhere who are seeking safe and promising investments.

Dollars invested by the state in the work of the Geological Survey will return to her thousands of dollars in the saving, the utilization and the development of our resources. The enormous profit derived by the older states from expenditures on similar geological surveys in unquestionable. In a new state like North Dakota the benefits should be even greater.

I trust that hereafter the state will amply provide for the vigorous prosecution of this important work. It is with pleasure that I turn over the portion of my work connected with the Survey to Dr. Frank A. Wilder, for I believe that North Dakota is fortunate in securing as a director of the State Geological Survey one so well qualified by training and experience for the prosecution of this work.

Respectfully,

E. J. Babcock,
Professor of Chemistry and Dean of the School of Mines.

State University of North Dakota,
November 1, 1902.

Hon. David Bartlett, President of the Board of Trustees of the State University of North Dakota:

Dear Sir: I have the honor to submit herewith the second biennial report of the State Geological Survey of North Dakota. In taking up the work which the pressure of other duties compels Prof. Babcock to relinquish, I am very materially aided by the excellent introductory study made by him of the coals, clays and the waters of the state. The hearty appreciation of the purpose and previous work of the Survey which I find everywhere through the state gives the greatest encouragement to those who are actively associated with the Survey's affairs.

Scope of the Survey.—As definitely stated in the law under which the Survey was organized, it is entrusted with the complete and thorough geological study of the state, and particularly with those lines of research that promise to develop its mineral wealth. Theoretical problems, however, are not to be neglected. The stratigraphic and topographic features of the state are to be studied and properly mapped, and the historical development of each is to be explained. A proper order for work is suggested in the statute of organization in which primary stress is laid on the economic problems, to which the attention of the Survey is specifically directed. It shall be my endeavor, therefore, to direct the initial work of the Survey so that the value of the natural resources of the state may be known, and at the same time, so far as practicable, to collect other data bearing on the theoretical problem that the state presents, which shall furnish matter for later publications.

With the consent of the Board of Trustees, the first bulletins of the Survey will treat of the coals and clays, the water resources with special reference to irrigation, the building stones and cement materials; probably in the order named. Preliminary reports as thorough as the time and means available allow will be made, and these will be followed by more minute studies in which the convenient unit of area will be the county. After the completion of the series of county reports, material will be available for exhaustive topical papers.

In addition to what may fairly be termed the positive work of the Survey, namely the pointing out of the mineral resources of the state which justify investment, a great deal of the survey work, just as important in its bearing on the development of the state, is negative in its nature, consisting of making examinations for interested citizens which result in assuring them that the proposition which they have submitted will not warrant development. In this way the survey saves to the state large sums of money and prevents many hopeless speculations which would delay the development of justifiable projects.

Finances of the Survey—The finances of the Survey are handled in accordance with the most conservative business methods. For local and office expenses no money goes through the hands of the State Geologist or his assistants, but all necessary expenditures are made through your Secretary. In the field, vouchers are taken for all sums spent and these are filed with your Secretary, together with itemized statements, the correctness of which is sworn to before a notary. These statements and vouchers are subject to inspection at any time at the office of the Secretary of the Board of Trustees.

Co-operation with the United States Survey.—I take pleasure in reporting the friendly attitude of the United States Geological

Survey, and the cordial co-operation which began some years ago is continued and extended during the present year. Some of the results obtained from this joint investigation are included in the accompanying report, though subsequent reports will profit more largely from these investigations which are this year only begun. By means of this co-operation the State Geologist was this year able to enlarge the scope of his work, while during the next field season with an enlargement of the state appropriation to meet the liberal policy of the United States Survey, the field and office work may be trebled in amount and increased materially in efficiency.

Contents of Bulletin No. 2.—The present volume contains a preliminary report of the lignite coals of the state, prepared by the State Geologist, assisted by Mr. L. H. Wood, A. M. Mr. Wood is a graduate of the University of Michigan and is engaged in advanced geological study at the University of Chicago. His report on the lignites of Ward county and the Ft. Berthold agency will be found painstaking and accurate and a valuable aid in the development of an important section of our state. The large sums that are being invested in thoroughly equipped mines about Minot and Kenmare are fully justified and should bring good returns to the investors, and build up in this country a permanent industry of considerable magnitude. The desirability of developing industries like this in an agricultural community I have reviewed at length in a separate chapter of this report entitled, "The Significance of the Lignites to the State." Mr. Wood personally visited a large number of localities away from the railroad where coal is won for local use, by stripping, and secured samples from which analyses were made, the results of which are given in his report. In a prairie country, where timber is lacking and distances to railroads often very considerable, the value of these lignite beds, scattered generally through the country, from which good fuel is obtained at a nominal cost, is very great, and they are proving one of the factors most favorable to a rapid opening up of this country. Mr. Wood's field expenses were very low, most of his traveling being by bicycle, and the state was fortunate in securing his services. For all of the sketches in this volume we are indebted to him. A more complete report on the geology of Ward county will be forthcoming in the proposed series, in which additional data will be published in regard to the coal of the county, as well as information, some of which is already in hand, in regard to clays, water resources, building stones and gravels, and the interesting glacial problems that are associated with the valleys of the Mouse and Des Lacs rivers, and the Coteau du Missouri.

The portion of the present volume prepared by me, consists of a preliminary report on the lignites outside of the area studied by Mr. Wood. After visiting the larger mines of Ward county with Mr. Wood, I went to Williston and studied the exposures of lignite and clay along the Missouri river, and on the Stony, Muddy and Sandy creeks. Additional information in regard to coal farther north in Williams county, east along the Yellowstone, and south in Wallace county, was obtained from the county surveyor, Mr. J. C. Field. Before the publication of the next report it is hoped that a representative of the Survey may be able to visit these localities and prepare extended descriptions. Returning to Minot, and going south on the "Soo" road, a day was spent about Velva, visiting a promising sandstone quarry one mile from town, and gathering data in regard to lignite. By wheel a trip of fifty miles was then made over the Coteau du Missouri, to Coal Harbor, with a stop at the coal mines ten miles southwest of Velva, along the Coteau. From Coal Harbor as a center, trips were made to the old mines about Ft. Stevenson from which coal for the agency and Indian school were taken for years, and to exposures along the Missouri river and neighboring creeks. Opportunities for irrigation along the Missouri were studied and material collected for joint reports to the state and the United States. From Coal Harbor to Washburn the trip was made by bicycle, and from Washburn trips were made to a number of mines and coal exposures. The large mine at Wilton was studied carefully, as a fair sample of what can be done in the way of developing the lignites of the state. Through the courtesy of the mine owners and superintendent, ample opportunity was given to study the situation both above and below ground, and to look over the mine maps. In the minds of investor and mining engineer certain practical questions in regard to conditions for mining are uppermost, and in the chapter on the extent and availability of the lignite, many of these questions are answered. They have to do with the amount of water in the mines, the nature of the roof and floor, and the peculiar advantages and disadvantages that the lignites offer as a mining proposition. The mines at Sims, New Salem and Lehigh were also studied with these questions in mind, and many localities north and south of the railroad in the vicinity of these towns where coal is exposed were visited. In connection with the special irrigation problem undertaken for the United States Survey, two weeks were spent along the Heart and Green rivers, and two weeks along the Little Missouri, working north and south of Medora. sixty miles in each direction. The results of this work must be in the main reserved for a later volume, though much data with reference to the lignites collected on these trips is submitted herewith.

Next to their abundance and availability, the worth of the lignites as a fuel is a subject worthy of careful investigation. This volume contains a report of the work done along this line up to date. Fortunately the Survey is greatly aided in getting at the facts by the careful observations and experiments of a number of manufacturing and state institutions. The chapter devoted to this subject naturally divides itself into two heads: the laboratory tests and the practical boiler tests, where lignite is burned under varying conditions, for the generation of steam and general heating. The results obtained are exceedingly satisfactory to those who are interested in the development of the lignite industry, and when published and properly circulated should stimulate the demand for lignite both in and out of the state.

The chapter on mineral statistics is to be a regular feature of the biennial bulletins of the state, and arrangements are being made so that in forthcoming reports data may be collected and tabulated with great accuracy, the State Geologist co-operating with the department of mineral industry of the United States Survey. This year the report on the output of coal and clay goods can not claim to be complete, but it is believed that the output of products based directly on the natural mineral wealth of the state is under rather than over stated by the figures given.

Professor Babcock contributes to the report a practical paper on the surface waters, especially those of the Devils Lake region, and makes suggestions in regard to the construction of wells that should be brought to the notice of great numbers of those who are establishing new homes in the state.

The chemical work of the Survey has been carried out by Professor Babcock and Miss Bisbee. The amount has been considerable as the number of analyses given shows. The calorimetric tests of the lignite have been made by them also. All of this work is of the highest practical value, and the expense involved has been slight in comparison with the services rendered. In presenting a report of this nature, a limited amount of technical knowledge of the subject on the part of the reader must be assumed. While it is desirable to present every subject as clearly and simply as possible, to enter into a detailed explanation of geological phenomena, which are well understood and are adequately described in the literature on the subject, is not practical. An attempt to treat the present report in this way would increase its bulk five-fold. To those who desire a simple statement of the general geological phenomena of the state, I take pleasure in recommending Prof. Daniel E. Willard's book, "The Story of the Prairies," which may be obtained from the author at Mayville, North Dakota.

Number and Distribution of Reports.—I would recommend that the edition of the bulletin herewith submitted be eighteen hundred. A copy should be sent to each state official and to each newspaper, to certain of the county officers who are likely to be called on for information that it contains, and to all public and school libraries in the state. A considerable number must be held to meet the requests of persons both in and out of the state who desire information along the lines treated of in the report, and a number nearly as large must be sent to the various state and national geological surveys both of this country and Europe. In return for these volumes, the Survey receives for the state an annual addition to its library numbering nearly fifty volumes, with technical papers and magazines of great value. It is further recommended that of the eighteen hundred copies three hundred be bound as separate papers, to supply requests for information along single lines dealt with in the report.

Presentation of the Mineral Industries and Wealth of the State in Technical Papers.—A very pleasant part of the work of the State Geologist has consisted in answering inquiries and preparing articles on the mineral wealth of the state for technical journals. During the last year the mining public has had its attention directed to the lignites of North Dakota by the success of the Washburn and other mines, and news from the lignite fields finds a ready hearing. There is no danger at present of exaggerating the opportunities that the lignite offers as a mining proposition, and the greater the publicity given the situation the greater the advance of the industry in the state..

Needs of the State Survey.—Interest in the work of the Survey on the part of the people in both city and rural communities is very manifest and genuine. At present its organization is ample, its relations with the United States Survey most favorable and the opportunity is offered for extensive and vigorous work. Most of the states of the Union support geological surveys by appropriations that are from ten to fifty times as large as that enjoyed by the Survey of North Dakota, and many of them have mineral wealth which needs developing, greatly inferior to that possessed by our state. The Survey has passed the preliminary stages in which it is well to be extremely conservative, and is ready with the proper support to contribute largely to the building up of the material prosperity of the state.

Work Outlined for Next Year.—Co-operating with the United States Geological Survey the study of lignite and irrigation will be pushed. Three parties are planned for, each to contain a surveyor and a geologist, to follow all of the streams in the lignite area, note the abundance and quality of fuel ,the amount of land that can be irrigated and the lift necessary to raise the water from the nearest stream or possible reservoir. The systematic study of the clays of the state will be continued, and preliminary work on stone begun. Topographic work, which is essential as a basis for the study of the irrigation problem in the western part of the state, will be undertaken in connection with the United States Geological Survey.

Attitude Toward the Agricultural Survey.—At the last meeting of the legislature a subordinate survey was organized under the auspices of the Agricultural College, to undertake field work which has a direct bearing on agriculture. It is the desire of the State Geological Survey to extend to the Agricultural Survey its aid, and enable it as fully as possible to realize the aim of its organization, and proposals have been made with a view to determining how the State Survey may best advance the interest of this allied line of research. The necessity of intimate relationship is realized by all the workers in the field, and the State Geologist would suggest for the consideration of your honorable body, whether the Agricultural Survey should not be affiliated as a definite department of the State Survey, which, primary in its organization, includes within its scope research along all of these lines.

Regulations Governing the Distribution of Information Gathered by the Field Staff.—In connection with the distribution of data in regard to the mineral resources of the state, two fundamental principles can be laid down.

First—Data gathered for the state and at the expense of the state is not to be given to any individual or company until it has been published and made available for all of the citizens of the state.

Second—It is the duty and is an important part of the work of the State Geologist to direct capital to the resources of the state that justify development.

In view of these principles a definite policy which the field staff of the Survey should carefully regard, seems apparent; and I would herewith submit the following regulations touching this point for your acceptance or revision:

No member of the field staff of the State Geological Survey shall make public information in regard to the undeveloped mineral resources of any locality or localities in the state, or in regard to sites suitable for irrigation, until a report on the same has been given to the public in a bulletin of the State or United States Geological Survey, or in some other official state or national publication.

When such data has thus been given to the public, it shall be the duty of the field staff of the Geological Survey to assist investigators who seriously propose developing the resources of the state in any reasonable way that does not conflict with their other duties; provided, that no item of expense for such aid shall be borne by the state.

Aid which may be rendered investigators under these regulations will, it is believed, result wholly and fairly to the advantage of the state. For the field staff to refuse their aid altogether to outside parties seeking to gather information preliminary to investments would result in preventing investment, or in bringing in specialists from eastern states whose knowledge of the local field must necessarily be limited, and their ability to present the resources of the state limited accordingly.

Respectfully submitted,
FRANK A. WILDER,
State Geologist.

University, November 1, 1902.

The Pembina Cement Company's Mill.

MINERAL STATISTICS

Summary of Mineral Output from January 1, 1901, to January 1, 1902.

Lignite	$ 407,170
Brick	165,662
Cement	10,000
Stone	5,000
Gravel	

The estimated output of mineral products for the coming year, 1903, based on the increase in equipment already made, and a demand equal to that of the past year, is not less than $1,000,000.

With this biennial report the Geological Survey begins the publication of the mineral statistics of the state. The data presented herewith is incomplete at a number of points, but the output is always under rather than over estimated. Steps are being taken to place the State Survey in close touch with every mine, brick-yard and manufacturing establishment using native mineral for raw material throughout the state, and succeeding reports will contain complete statements of the state's mineral productions.

LIGNITE.

For a number of years the United States Geological Survey, through its bureau of Mining and Mineral Resources, has published yearly statements of the output of coal in North Dakota, their report beginning with the year 1889, and coming down through the year 1901. The data given in these reports, though carefully compiled and collected, is necessarily incomplete, for many of the smaller mines are known only locally and their output could not be determined. From 1895 to 1900 at least the figures given in these reports are doubtless too low. The extraordinary increase in the output of lignite in 1902 over the output for 1901 as shown in the accompanying tables, is partly real, and in part apparent only. Some of the larger mines now producing were not in operation in 1901, and the output during last year has actually nearly doubled. A more minute knowledge of the lignite deposits of the state renders possible a statement of the output of localities that were not reported in 1901.

The following tables, taken from the United States bulletin, "The Production of Coal in 1901," present interesting data:

Coal Product of North Dakota in 1901, by Counties.

COUNTY	Loaded at mines for shipment,—Short tons.	Sold to local trade and used by employes.—Short tons	Used at mine for steam and heat.—Short tons.	Total product.—Short tons.	Total value.	Average price per ton.	Average number of days active.	Average number of employes.
Burleigh and Emmons	35,836	4,306	4,712	44,854	$ 50,111	$1.12	285	69
M'Lean and Oliver	.....	1,516	....	1,516	3,016	1.99	275	4
Morton........	48,250	4,300	300	52,850	64,035	1.21	180	68
Stark..........	16,650	2.050	....	18,700	19,237	1.03	193	25
Ward..........	33,928	14,603	150	48,618	77,752	1.60	160	114
Total	134,664	26,775	5,162	166,601	$ 214,151	$1.29	198	280

Distribution of the Coal Product of North Dakota from 1889 to 1901.

YEAR	Loaded at mines for shipment.—Short tons.	Sold to local trade and used by employes.—Short tons.	Used at mine for steam and heat.—Short tons.	Total product.—Short tons.	Total value.	Average price per ton.	Average number of days active.	Average number of employes.
1889............	18,610	10,297	.....	28,907	$ 41,431	$ 1.43	.....	....
1890............	....	30,000	......	30,000	42,000	1.40	.....	....
1891............	....	30,000	......	30,000	42,000	1.40	.....	....
1892............	38,000	2,725	.....	40,725	39,250	.96	216	54
1893............	47,968	1,612	50	49,630	56,250	1.13	193	88
1894............	37,311	4,4-0	224	42,015	47,049	1.12	156	77
1895............	35,380	3,617	......	38,997	41,646	1.07	143	62
1896............	71,447	6,183	420	78,050	84,908	1.09	166	141
1897............	65,032	10,458	1.756	77,246	83,803	1.08	168	170
1898............	71,223	11,525	2,147	83,895	93,591	1.12	187	151
1899............	77,731	20.788	290	98,809	117,500	1.19	154	210
1900............	106,584	21,729	1,570	129,883	158,348	1.22	142	326
1901............	134,664	26.775	5,162	166,601	214,151	1.29	178	280

Coal Product of North Dakota since 1884.

YEAR	SHORT TONS	YEAR	SHORT TONS
1884	35,000	1894	42,015
1885	25,000	1895	38,997
1886	25,955	1896	78,050
1887	21,470	1897	77,246
1888	34,000	1898	83,895
1889	28,907	1899	98,809
1890	30,000	1900	129,883
1891	30,000	1901	166,601
1892	40,725	*1902	296,800
1893	49,630		

The great increase which is shown for 1902 is due largely to the development of the large mines at Wilton, Burleigh county, at Kenmare, in Ward county, and the increased capacity of the mines in Morton and Stark counties. A great number of smaller mines throughout the entire lignite area were opened up, the coal in most of them being secured by stripping. As time goes on, and the mines work back from the banks of the streams or draws where they are commonly located, the overburden increases and instead of winning the coal by stripping, drifting is begun. As the population increases many of these surface mines develop into underground workings of considerable magnitude. This transformation is at present taking place in a number of localities.

An attempt has been made to estimate the output of a number of the local workings. These localities were personally visited and the figures given are under rather than over the truth. There are hundred of localities in North Dakota where farmers and ranchmen dig their own lignite and pay absolutely nothing for the privilege. It is impossible to estimate the amount of coal so mined though the total is considerable.

The selling price of lignite at the mine varies from nothing to a dollar and a half. Where lignite costs nothing, the labor of the farmer who does his own mining, is not considered. If this were taken into account the lowest selling price would be but a few cents, for thousands of tons are won along streams where the floods of fall and spring do all the stripping. The selling price, however, does not represent the true value of the lignite to the community. A truer standard would be the cost of fuel to the state if lignite were absent, necessitating the use of other fuel. By this standard the values given in the tables below would be multiplied by four or five.

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*The output for 1902, as shown above, is based on data collected by the State Survey.

Summary by Counties of Lignite output for 1902.

COUNTY	Loaded at mine for shipment.	Sold to local trade.	Total product.	Total value.	Average value per ton.
Billings	....	* 5,000	5,000	$ 4,000	$ .80
Burleigh	120,000	*10,000	130,000	169,000	1.30
Emmons	....	* 1,000	1,000	2,750	2.75
Mercer	....	* 3,000	3,000	2,400	.80
Morton	30,000	* 5,000	35,000	45,000	1.30
McLean	....	* 4,000	4,000	5,200	1.30
Oliver	....	* 3,000	3,000	2,400	.80
†Stark	45,000	*10,000	55,000	66,000	1.20
Ward	76,800	*19,000	57,800	107,520	1.40
Williams	....	* 3,000	3,000	2,400	.80
Total	....	....	296,800	$407,170	....

In the number of mines that are shipping coal by railroad Ward county easily leads, but since it contains the large Washburn mine, Burleigh county leads in output. During the fall the selling price advanced sharply throughout the state, from $1 to $1.25 and at times to $1.40 per ton at the mines. The present surface equipment of mines in Ward county is sufficient for a much larger output than as estimated last year, and as underground work is advancing rapidly the output for next year will doubtless show a remarkable increase.

BRICK.

The output of clay goods shows a remarkable increase for the past year. At least two new yards were established in 1902. In spite of this, however, the state is probably using more brick than it produces, the additional supply coming from Minnesota. This condition is not natural, for North Dakota possesses immense quantities of the finest clays, easily available, with cheap fuel, and the state should ultimately become an exporter of brick and pottery in various forms.

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* Estimated.

† Including Hettinger.

The Red River Valley.—Grand Forks is the largest producing center in the state, with three large yards which have a combined yearly capacity of 15,000,000. Like all of the brick in the Red river valley the Grand Forks product is made by the soft mud process, and is not intended for a facing brick. The Swanson yard at Fargo has an annual output of 1,500,000. The demand exceeded the supply throughout the Red River valley during the past year, and the season of 1903 promises to be a very active one.

At Dickinson.—The development of the promising plant at Dickinson is of general interest to the state; for it means a home supply of high-grade facing and fire brick. For the city in which it is located it means a considerable addition to business. The following detailed statement of output shows the variety of product of the Dickinson Fire and Pressed Brick company.

Brick made from April 1 to October 30, 1902.

KIND	NUMBER	VALUE
Pressed facing and common	934,000	$11,208.00
Ornamental brick	3,500	350.00
Well curbing brick	14,000	168.00
Fire brick, plain	298,000	3,576.00
Fire brick, skew backs	4,000	200.00
Fire brick, side arch	10,000	120.00
Fire brick, end wedge	16,400	196.80
Fire brick, kiln floors, 4x4x12 inches	650	65.00
Fire brick, coke oven floor tiles, 12x12x3 inchcs	1,150	230.00
Fire brick tiles, 4x10x24 inches	30	9.00
Fire brick tiles, 15x18x3 inches	32	9.60
Fire brick boiler arches	98	245.00
Fire brick bullheads	2,500	75.00
Window sills and caps, 4x10 inches by 4 feet	4	8.00
Total	1,354,364	$16,460.40
Coal mined, 1,014 tons	....	1,521.00
Total value	....	$17,981.40

The yard will remain in operation during the entire year. The simple and convenient manner in which fuel is secured for this yard has been described under lignite deposits about Dickinson, Stark county, and the clay pit with lignite seam is shown in Plate XXX.

The following table includes all of the yards from which reports could be obtained last year:

Brick Yards.

FIRM NAME AND LOCATION	Founded.	Annual output.	Total value.	Months in operation.	Average value per M. at kiln.	Men employed.	Boys employed.
Grand Forks—							
Dinnie Bros	......	5,000,000	$ 35,000	4	$7.00	11	2
W. P. Alsip	......	5,000,000	35,000	4	7.00	12	..
Ed Hunter	......	5,000,000	35,000	4	7.00	12	..
Fargo—							
G. A. Swanson	......	1,500,000	12,000	3	8.00	12	..
Dickinson—							
Dickinson Pressed Brick and Fire Clay company	......	1,400,000	16,460	9	11.30	....	..
Burlington—							
Mouse River Lignite Coal company	......	1,139,000	9,112	3	8.00	20	..
Bismarck	......	1,000,000	6,500	5	6.50	15	..
Williston—							
Metzgars	1902	300,000	2,500	3	8.50	12	..
*Brueggars	......	....	....	....	......	....	..
Washburn—							
Edward Cross	1902	300,000	3,600	1	12.00	8	..
New Salem—							
Bowser Bros	......	300,000	2,400	....	8.00	4	..
Bottineau—							
William Hall	......	850,000	6,250	4	8.00	13	..
Rolla—							
Philip Demars	1902	230,000	1,840	4	8.00	7	..
Total	......	20,880,000	$156,550	....	......	....	..

A detailed report of the brick industry of the state is reserved for the next biennial report.

PORTLAND CEMENT.

The works of the Pembina Portland Cement company are located on the Tongue river in Cavalier county, North Dakota. The deposits of raw material outcrop from the sides of the high bluffs adjoining the river. The material is secured by tunneling and is run from the quarry in mine cars to the kiln. It is a soft, argillaceous limestone, easy to mine and handle. It is of remarkably uniform composition and very free from objectionable impurities. Analyses show that this raw material has a composition very similar to that used in some of the best German cements.

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*No report was obtained from the Brueggar yard at Williston.

The factory is substantially built and equipped with high grade machinery. The most modern and improved appliances are used throughout. The whole plant is under one root with the exception of the engine house and the clinker storage rooms. The main building contains the crushers, driers, pulverizers, rotary kiln and conveying machinery. The plant is provided with rotary and upright kilns. From fifteen to twenty men are employed during the active season. Considerable work is done at the factory during the winter months. During the past year the output was 8,000 barrels. It is hoped that it will be increased to 50,000 during the coming year.

Two grades of cement have been made, namely, a high grade Portland and an exceptionally high grade natural hydraulic. The Portland is made by a somewhat different process from the hydraulic and from specially selected material. During the past year only one brand of cement has been put on the market. This is known as the Northern hydraulic and is in reality a semi-Portland. There is no other hydraulic cement known of such a high grade as the Northern hydraulic cements made by this company, since the clinkers from which it is made contain a large proportion of high grade Portland material. The cement is all ground unusually fine, a fact which adds much to its value in masonry and to its strength since it enables the cement to carry considerably more sand. From 95 per cent to 98 per cent of the cement will pass a 100 mesh sieve. (That is, 10,000 to the square inch.)

Many of the largest contractors have used this cement extensively and have pronounced it by far the best hydraulic cement they have ever used and many reliable builders have used it as a Portland. Its market is from Minneapolis and St. Paul westward to the coast. The industry is a new one, but it has worked its way well into the favor of cement consumers and those who are best qualified to judge of its merits, and it already enjoys an enviable reputation.

Tests of the Northern hydraulic cement made by the Pembina Portland Cement company:

THREE PARTS SAND, ONE PART CEMENT.

7 days.	28 days.	3 months.	6 months.
100 pounds.	200 pounds.	300 pounds.	400 pounds.

STONE.

Very little systematic quarrying has as yet been done in the state. The Stafford quarry, one mile from Velva, has furnished stone for a handsome and substantial building in that town. A sandstone which outcrops along the Missouri river has been utilized for foundations in Washburn. In Emmons county some sandstone has been used for building, especially at Linton. Small quantities of sandstone have been used at Dickinson.

Large sandstone quarries are practical, and a number of suitable locations only await a sufficient demand to justify extensive development.

The granite and gneiss boulders in the glaciated area are more important at present from an economic standpoint than are the native sandstones. Throughout the eastern half of the state, except in the Red river valley where surface boulders are scarce, they are used extensively for foundations and sometimes large buildings are constructed of them. They may be dressed easily and present a handsome appearance. The foundations of the buildings of the asylum for the insane at Jamestown show how effectively they may be used. Their cost varies with local conditions, but for many localities they should be considered as a possibility before brick for foundations. At Jamestown, under the contract for the erection of the asylum buildings, the boulders were gathered, hauled, dressed to eleven-inch courses with sunk joints, and laid in the wall for $10 a cord.

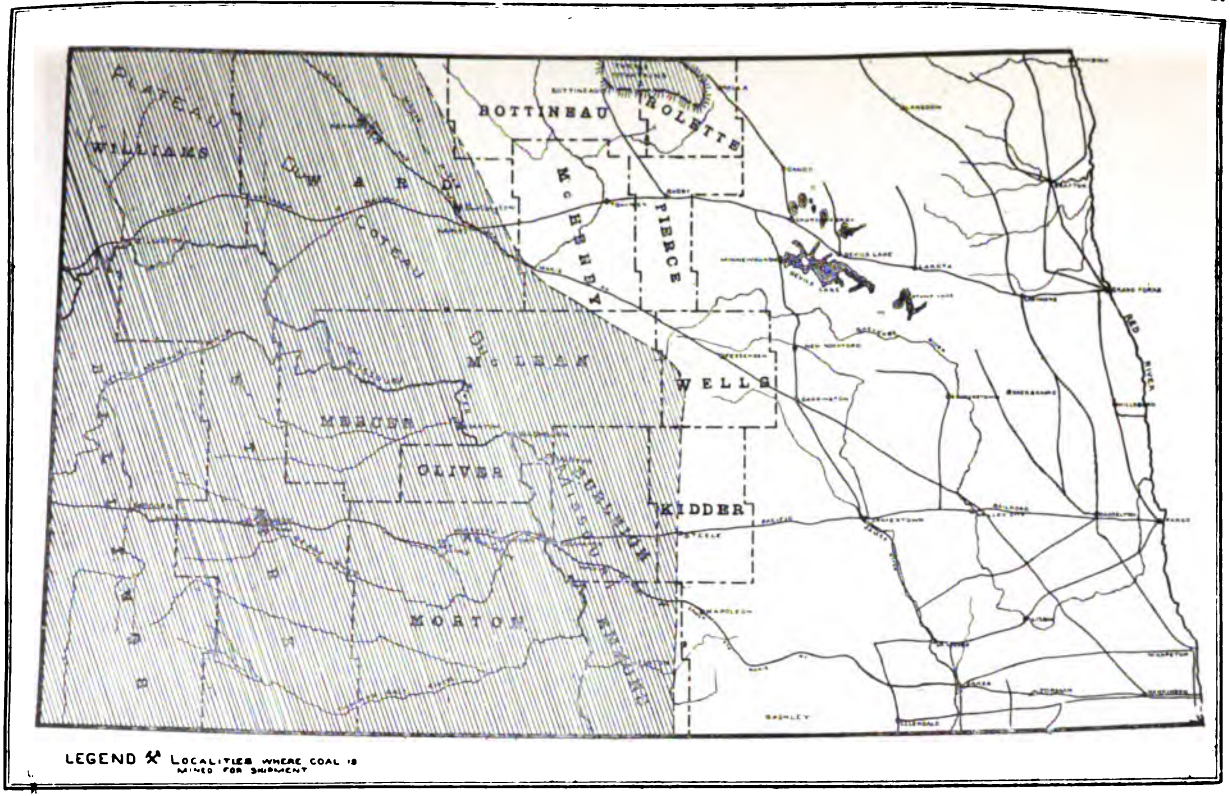
GRAVEL.

It is impossible to estimate the value of the great gravel deposits of North Dakota, from which thousands of cars are taken annually for railroad ballast. They are conveniently distributed throughout the state and with increase of population will justify careful study, for they will furnish the most available road material. The deposits at Jamestown, which are seen by every traveler from the car window, are but samples of dozens of others, some of which are already opened by the railroads.

POTTERY GOODS.

As yet the valuable pottery clays of North Dakota are wholly undeveloped. They are destined, however, to figure conspicuously in the mineral statistics of the state.

Plate III.



A Map Showing Approximately the Area in Which Lignite Occurs in Quantities Sufficient To Be of Economic Importance. The Lignite Area Is Marked by Diagonal Lines.

THE LIGNITE COAL FIELDS
OF
NORTH DAKOTA

EXTENT OF THE LIGNITE AREA

While thin seams of lignite have been recognized in the eastern part of the state and have been described* at the southern bend of the Cheyenne river, in Township 135, Range 54, Section 32, which lies about twenty-five miles southwest of Valley City, and at other points nearly as far east, workable seams are not found, except in the Turtle mountains, till the center of the state is reached. The plateau known as Turtle mountains is an outlier of the lignite area proper, which may be roughly bounded on the east by a line beginning at the northern boundary of the state and thirty miles east of the Minneapolis, St. Paul & Sault Ste. Marie R. R., and extending southeast to Harvey, thence south through Steele to the southern boundary. More minute study, aided by well borings which will doubtless be made as the country is settled, will probably shift this line east or west at certain points, thirty or forty miles. The state lines are its boundaries on the north, west, and south, while outside of the state the lignite continues in these three directions. Only this region, in which workable seams of lignite may reasonably be looked for, is included in this report under the term, lignite area. Even when so restricted it is of very great extent, equal to at least half of the state of Ohio.

It is highly probable that lignite does not exist in seams of workable thickness in every part of this region, but it is equally probable that the fraction of the area lacking lignite in seams three or more feet thick is a small one, not more than one-fifth of the whole. These seams may not all be available, either on account of depth, or some other difficulty in mining and throughout a considerable part of the region are so thoroughly concealed by glacial drift that, without a knowledge of the underlying formations and of the surrounding country, their existence would be unsuspected.

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* Upham in Monograph XXV, page 92, United States Geological Survey.

TOPOGRAPHY OF THE LIGNITE AREA

The surface of the lignite area presents considerable variety. Areas that would be regarded as topographic types could readily be chosen from the moraines of Coteau du Missouri; from the older drift west of the moraine; from the Missouri valley; from the driftless area about Dickinson, and from the Bad lands.

THE WISCONSIN DRIFT PLAIN.

The extreme eastern portion of the lignite area lies within the coparatively leveml plain of the Wisconsin drift, the deposit formed by the last great ice invasion. Like this plain throug out the eastern part of the state, it is moderately rolling, and rarely presents the extremely level surface that characterizes it in Iowa and Illinois. The interesting valleys of the Mouse and des Lacs rivers, which lie within this area, will be briefly described by Mr. Wood in his report on Ward county.

Rising rather sharply from the Wisconsin drift plain is the Coteau du Missouri, along the edge of which the lignite outcrops at a number of points which will be described in the subsequent text. The Coteau was studied along the Great Northern and Northern Pacific railroads, in a trip across country from Velva to Coal Harbor, and in a number of excursions back from the "Soo" road, and at all of these points its characteristics were quite constant. The rather sharp rise of its eastern face may be illustrated by the elevations of stations on the Great Northern. Des Lacs, 1902 feet above the sea, is on the prairie level, three hundred and fifty feet above Minot, which lies in the valley of the Mouse river. Berthold, twelve miles farther west, has an elevation of 2,087 feet. Wallace, six miles farther, is 2,187 feet high. From Wallace to Delta, a distance of five miles, an ascent of seventy-six feet reaches the crest of the Coteau. From this point the descent of the railroad is gradual to the west, crossing the outer or Altamont moraine of the Wisconsin drift, and reaching the level of the lower terrace of the Missouri river at Williston. The upland level, however, rises gradually toward the west.

THE MORAINES OF THE COTEAU DU MISSOURI.

Under this term is included a region twenty miles wide, lying about midway between the Missouri river and the "Soo" road in the northern half of the state, then with the river bending toward the south and continuing thirty or forty miles east of it, to the southern boundary. The region is strongly rolling, poorly drained, abounding in lakes and sloughs. This "hill country," as it is commonly called, is well grassed and will ultimately become a thriving dairy district, though now practically without settlers. Although boulders are abundant they present no greater difficulties to agriculture and grazing than have been overcome under similar conditions in the older states.

THE OLDER DRIFT WEST OF THE COTEAU.

A definite attempt to correlate the older drift outside of the Wisconsin moraines, with the Iowan, Kansan or pre-Kansan which have been differentiated farther south, has never been made, and while some data bearing on the question was collected during the past summer, an attempt to solve this problem will be left for a later report, and the general term of "older drift" only will be used. This drift, which is well exposed in railroad cuts about Washburn and along the Missouri river from Nelson to Chilcot, is highly oxidized and above it at various points, notably near Wilton in Burleigh county, were deposits of fossil bearing loess. Its drainage is nearly perfect and the creek valleys wide, with very gradual slopes. The drift is generally thin and its topography is influenced largely by that of the underlying Laramine shales.

THE VALLEY OF THE MISSOURI RIVER AND ITS LEADING TRIBUTARIES.

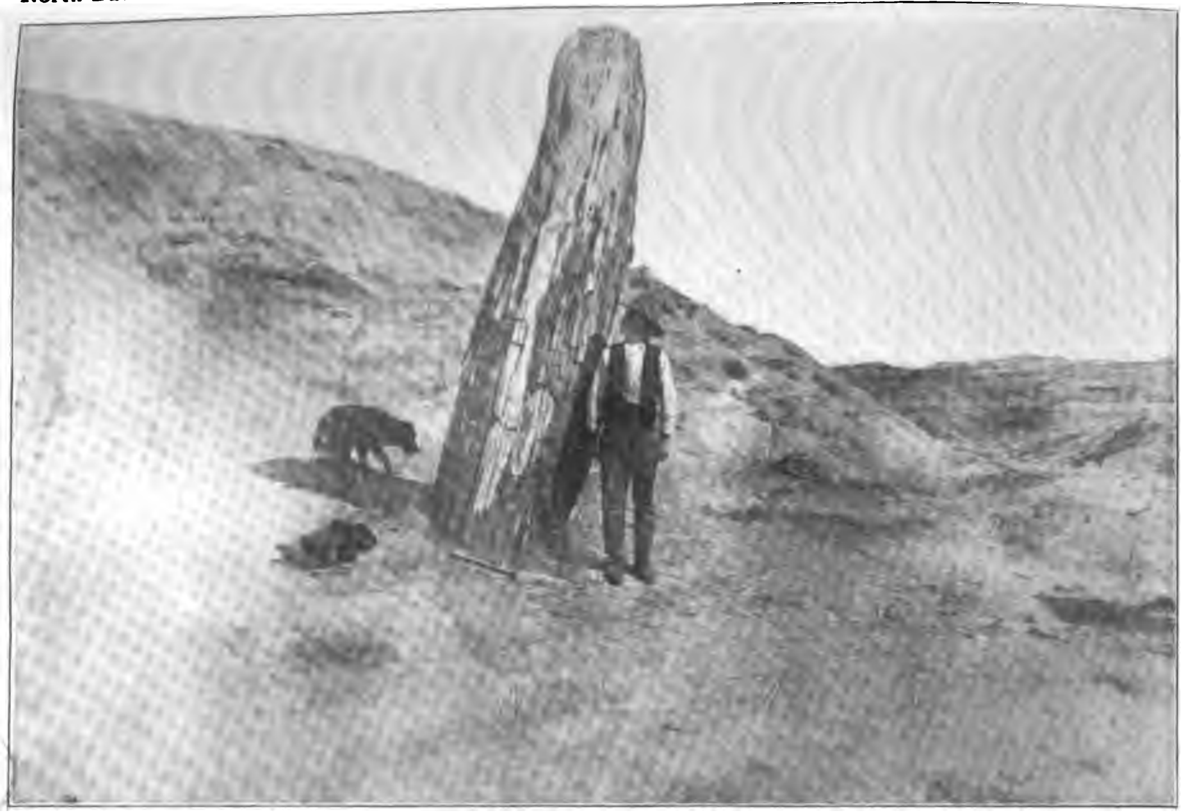
The Missouri valley is the most significant topographic feature within the lignite area. In the narrowest sense it is three miles wide, and three hundred feet deep. In reality, however, the stream affects the slope of the land for a considerably greater distance on either side. In the valley proper are well marked terraces. Similar terraces also characterize the valleys of its leading tributaries. During the past summer these were studied along the Little Missouri, in southern Billings county. Here three benches, at varying heights above the flood plain, are well developed. The lowest is twenty feet above high water mark, and is composed of sand, loam, and gumbo, certain parts appearing very fertile, while other regions promise little to the agriculturist. In width it varies from a fourth to half a mile. While the flood plain is beautifully wooded, trees do not flourish on any of the terraces. The second terrace is 100 feet above water level and is equal in extent to the first, while the third, twenty-five feet higher, is perhaps larger than either of the others. These terraces are generally faced with steep bluffs, and, like the country back of them are cut up into the "breaks," which are the characteristic feature of "Bad Land" topography.

THE BAD LANDS.

This region, perhaps more interesting to the general student of geology than any other portion of the state, constitutes the very heart of the lignite area, and for the bad lands Medora may fairly be taken as the center. The sharp, freshly cut banks giving vertical sections of hundreds of feet, which characterize bad land topography are especially adapted to reveal the mineral wealth of this portion of the state.

It is the purpose of this paragraph to discuss merely the topography of the Bad Lands. The nature and stratigraphic relationships of the clays, sands and lignites of which the strata are composed, will be considered elsewhere. The term "bad lands," originating as it did with the early French explorers who found these lands difficult to travel over, and hence "bad," has often been misunderstood. The soils, consisting of Cretaceous clays and wash from them, are generally fertile, and except where the slopes are so steep that the wash from torrential rains prevents the accumulation of vegetation, are well grassed Large stretches of country in the so called "bad lands" have a slightly rolling surface, and so far as topographic considerations are concerned are in every way fitted for agriculture. Perhaps one-half of Billings county, south of the Northern Pacific railroad, where the typical bad lands are located has no greater surface slope than is desirable for drainage. Extending back from the Little Missouri river gradually for four or five miles are the "breaks," a country so thoroughly cut up by erosion, so broken into pyramids, domes and flat topped buttes, that it is extremely difficult and often impossible to traverse it on horseback. In the breaks, vegetation is scant, the steep sides of the draws and buttes showing the bare, banded Cretaceous clays, with here and there a streak of sand or ironstone.

Rising above the average level of the bad lands are the low and high buttes. The low buttes rise to a height of one hun-



A Fossil Tree Trunk, Standing Where It Grew, Found Twenty-Five Miles North of Sentinel Butte.

dred and fifty feet. Many of them are flat topped and reach a very uniform elevation. They are well developed just north of the town of Sentinel Butte. The high buttes are scattered at intervals of eight or ten miles over southern Billings county, and less frequently are found farther north and east. Among them are the Camels Hump, Sentinel Butte, Square Butte, Bullion, Rocky and Black Buttes. All of these except the Camels Hump have flat tops, some of them a square mile in extent. Bullion Butte is perhaps the largest of those mentioned, its base occupying nearly a township. They usually rise abruptly to a height of four hundred feet above the surrounding country. Some of them, like the Camels Hump, are surrounded by a group of the lower buttes. The cross section shown in plate VI shows the relative heights of the low and high buttes, their elevation above the surrounding country being greatly exaggerated by the scale upon which the sketch is drawn.

As already indicated, the contrasts in elevation taking the area as a whole, are considerable. Except along the streams and about the buttes the changes in elevation are gradual, and the driftless area in which contrasts are most marked, taken as a whole, instead of being regarded as rugged would be called strongly rolling. Sharp ascents and vertical faces, however, characterize the buttes. Sentinel Butte is 400 feet higher than the station of the same name four miles away, and one-third of the ascent is made within half a mile of the butte, the last fifty feet being vertical at many points.

The following tables giving elevations along railroads illustrate fairly the elevations in the lignite area. Towns printed in italics are in river or creek valleys, while those in ordinary type represent fairly the upland elevation for the country in their vicinity.

ELEVATIONS FROM EAST TO WEST ON THE GREAT NORTHERN R. R.

DISTANCE BETWEEN STATIONS	STATIONS	ELEVATIONS
	Minot	1,557
16		
	Des Lacs	1,902
25		
	Delta	2,262
34		
	White Earth	2,092
8		
	Tioga	2,237
40		
	Williston	1,859

ELEVATIONS FROM EAST TO WEST ON THE NORTHERN PACIFIC R. R.

DISTANCES BETWEEN STATIONS	STATIONS	ELEVATIONS
	Mandan	1,644
35		
	Sims	1,959
64		
	Dickinson	2,401
40		
	Medora	2,261
17		
	Sentinel Butte	2,703
11		
	State Line	2,811

ELEVATIONS ON THE "SOO."

DISTANCES BETWEEN STATIONS	STATIONS	ELEVATIONS
	Harvey	1,592
51		
	Velva	1,525
21		
	Minot	1,557
50		
	Kenmare	1,799
32		
	Portal	1,954

THE TURTLE MOUNTAINS.

The high rolling plateau that bears this name is crossed by the northern boundary of the state and lies east of the Coteau du Missouri a hundred miles, having been separated from this main mass of late Cretaceous clays by pre-glacial erosion. The longer axis of the plateau extends about forty miles east and west, the shorter axis at right angles to this, being about thirty miles in length.

Beginning with a gradual ascent, the elevation increases rapidly near the top of the slope, till a height of four hundred feet above the surrounding country is reached. Morainic deposits, added to the unevenness due to pre-glacial erosion, give to the surface a very broken outline and adorn it with many attractive lakes. Among these is the beautiful little lake Metigoshe, situated near the center of the hills. Springs are abundant along the hillsides and feed perennial brooks.

The region abounds in fine farms, and is one of the many attractive agricultural districts of the state.

DRAINAGE OF THE LIGNITE AREA

Four-fifths of the lignite area lies within the drainage basin of the Missouri river. The Mouse river drains the remainder, with the exception of a very small section in the center of the state, near Harvey, which contributes to the waters of the James. The practically undrained region in the morainic tracts of the Coteau du Missouri lies for the most part within the area that naturally sends its waters to the Missouri and ultimately most of it will be drained in this direction, though the other streams just mentioned would doubtless profit in a small measure by this territory.

The Missouri crosses the lignite area nearly diagonally and the sharp cut banks so common along its course reveal vast quantities of this valuable fuel. From the east and north the river here receives no large tributaries, the most noteworthy being White Earth Creek in western Ward county, and Sandy Creek, which unites with it at Williston. Beaver Creek in Emmons county is reaching back into the morainic area, and is already a stream of some size. In addition to these are a multitude of smaller creeks from fifteen to twenty miles long, which have rather mature valleys in the older drift and are now cutting headward into the Wisconsin drift with great vigor.

On the south and west the tributaries of the Missouri are much larger, doubtless because of the fact that the glacial drift here but slightly affected topographic conditions. The Little Missouri is a stream of considerable size. Entering the state at the southwest corner, it flows north for one hundred and twenty-five miles, then turns to the east and after a course of seventy-five miles unites with the parent stream. During spring and late fall it discharges a very large amount of water, while during the summer its volume is variable, at times dwindling to a stream of small dimensions.

The same variations are characteristic of the Cannon Ball, and Knife and Heart rivers. The innumerable small tributaries of these streams, not indicated on any published map, ramify the region and readily draw off the down pour of rain storms which even in summer are often severe.

The lignite area abounds in living springs, most of which issue from the lignite itself. Unaided by artificial conditions the larger ones will often fill a four inch pipe with a strong stream. In the subsequent reports the locations of many of these springs will be noted. On account of these springs many of the creeks are perennial for a short distance from the parent stream. During the summer, the evaporation due to the heat and wind materially affects the amount of the water flowing in the creek channels and strong springs result only in forming a series of pools, separated by sand or gravel barriers through which the water seeps to a lower level.

The Yellowstone river unites with the Missouri so close to the western boundary that it is hardly a factor in the drainage of the state. Its broad valley, combined with its large volume of water render attractive the possibilities of irrigation along its course in this state, as well as in Montana.

In Wlliams and Billings counties a few lakes are indicated on the map and some shallow ponds actually exist. Billings county is free from drift and Williams county lies outside of the area of the Wisconsin drift, so that this indication of incomplete drainage can not be ascribed to glacial agencies. Where actually seen these ponds could be accounted for in one of two ways. A tributary stream at times is a more active erosive agent than the parent stream and deposits debris at their point of meeting sufficient to form a barrier behind which a considerable quantity of water may be held. In the region under consideration barriers in stream channels are more commonly formed by the slipping of the Cretaceous clays. This tendency of the clay to slide in large masses is noticeable throughout the lignite area, and shows itself commonly in crescent shaped depressions on the hillsides.

The drainage of Ward county is given in the report which follows.

STRATIGRAPHY

GENERAL RELATIONSHIPS OF STRATA.

The restriction of the term "lignite area" to the region in which workable seams of lignite may be found greatly simplifies the stratigraphic series, and practically reduces this chapter to a consideration of the Laramie and of the drift. The thin seams of lignite farther east, along the Cheyenne river, regarded by Upham as possibly belonging to the Benton* are by this definition excluded from the discussion. The age and nature of the formations are shown in the following table:

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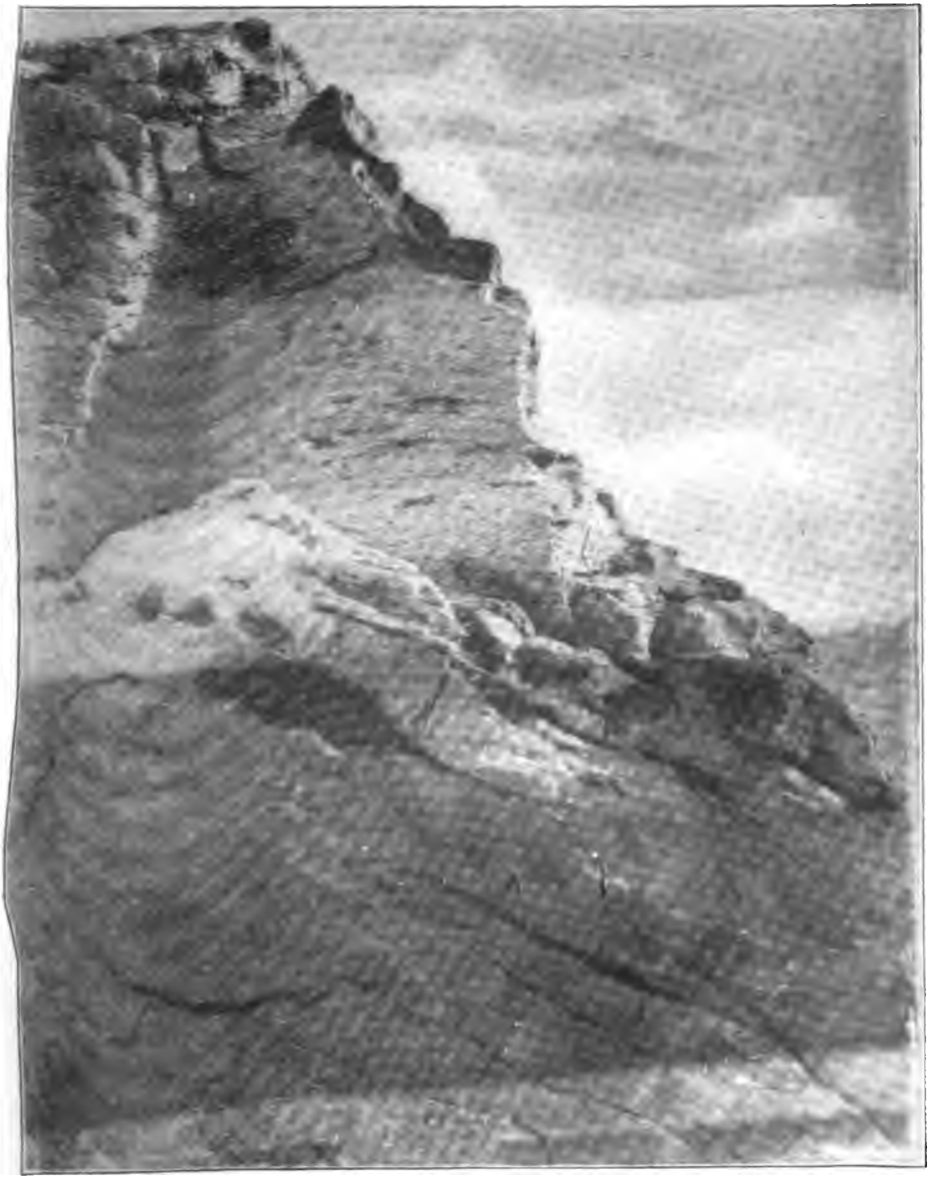
* U. S. Geological Survey, Monograph XXV, page 92.



Sandstone at the Top of Sentinel Butte.

UNIV. OF MICH.

GROUP	SYSTEM	SERIES	STAGE	SUB-STAGE	FORMATION
CENOZOIC	PLEISTOCENE	RECENT			ALLUVIUM
		GLACIAL	WISCONSIN		DRIFT MORAINES GRAVELS
					LOESS
			KANSAN?		DRIFT
MESOZOIC	CRETACEOUS	UPPER	LARAMIE		LIGNITE CLAYS SANDSTONES
			FOX HILLS?		SANDSTONE

The table just given includes the surface formations only. Deep well borings would bring to light under these, the lower Cretaceous and other members of older series. It is the purpose of the present report to consider only exposed formations, the discussion of underlying series being better left for a subsequent report when the stratigraphy of the state as a whole can be considered.

THE FOX HILLS SANDSTONE.

Todd, in Bulletin 144 of the United States Geological Survey has referred certain sandstone in southern Burleigh county and northern Emmons county to this formation. He says: "The presence of Fox Hills sandstone is shown by the capping of a butte encircled by Long Lake, just outside of the moraine, also by the conspicuous outcroppings along Sand creek, a steam flowing into the lake from the south, and about the borders of the tableland southwest. The same formation is similarly developed along Long Lake creek, which, rising near Long Lake, flows southwest in a large valley to the Missouri river near old Fort Rice." A sandstone which he regards as Fox Hills, is found ten or fifteen feet below the surface north of Steele.*

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*Bulletin 144, United States Geological Survey, page 55.

Reasons for referring the sandstone to this horizon are not given in the text.* Sandstone, apparently a local hardening of a more extensive seam of sand, occurs one mile west of Velva, at an elevation of about 1,700 feet, or lower than the sandstone at Steele by one hundred and twenty-five feet. The sandstone at Velva possesses no characteristics which prevent it being regarded as Laramie, nor does its elevation exclude it, for it is higher than the lignite mines at Minot. The reference of these elevated sandstones in Emmons, Burleigh and Kidder counties to the Fox Hills may fairly be regarded as very doubtful. Even if they are not so regarded, there probably exist areas of Fox Hills sandstone within the lignite area since pre-glacial erosion doubtless cut through the Laramie at points into the underlying Fox Hills. Exposures of this sandstone within the lignite area may never be found, since their line of meeting lies within a heavily drift covered area.

THE LARAMIE.

This, the latest stage of the Cretaceous, contains all the workable coal of North Dakota and is found in practically all the region previously defined as the lignite area, though its eastern border is buried, often deeply, by glacial drift. The difference in elevation of deposits of this stage actually exposed within the state is at least 1,400 feet. This nearly equals its maximum thickness known at any one point in the state. Its base lies not far below the Mouse river at Minot, 1,600 feet above sea level, while its greatest elevation is found in Sentinel and other "high" buttes, from 3,000 to 3,100 feet above the ocean. Its greatest thickness, safely shown by the Medora well to be more than 1,500 feet, occurs in the western part of the state, its vertical extent gradually decreasing toward the east, till at the edge of the Coteau du Missouri it drops off sharply, and continues as a relatively thin series beyond the Mouse river.

The Laramie formations consist of clays, sands, sandstone, lignite, and thin bands of hematite, clay-ironstone and shaly limestone. Perhaps three-fourths of the entire series consists of clay. Some of them are of remarkable purity, while arenaceous clays are not uncommon. Calcareous matter as a constituent is rare, though occasional layers contain fossil shells in great abundance. Analyses of Laramie clays from a few localities are given below:*

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*A personal letter from Prof. Todd, received since the above was written, says: "I inferred it (the age of the sandstone about Long Lake) from Hayden's statement that the Fox Hills sandstone, as he called it, was evident along Long Lake. See his statements of the distribution of Fox Hills in many places. From my personal knowledge of the Fox Hills and Laramie, I should say that the sandstone usually capping buttes in that region was very likely Laramie, and presume that the Fox Hills beds are lower down."

CONSTITUENTS	Minot	Bismarck	Williston
Silicon (SiO_2)	56.86	58.73	57.80
Aluminum (A_2O_3)	25.03	14.98	9.47
Iron oxide (Fe_2O_3)	6.11	5.63	3.16
Calcium (CaO)	0.71	2.10	7.91
Magnesium (MgO)	0.76	0.74	2.84
Sodium (Na_2O)	0.50	0.988	?
Potassium (K_2O)	0.016	0.16	
Water and volatile matter*	...	16.672	
Other matter	10.014	...	

* By subtraction. All very moist.

REMARKS—No. 2, not used; found on bank of Missouri river near Bismarck. No. 3, not used; associated with coal near Williston. In the laboratory furnace, No. 1 baked cream; No. 2, red, very firm; No. 3, cream.

The Laramie Clays.—Material is already partly in hand for a special report on the clays of North Dakota, in which the composition of the Laramie clays will be considered at length and their economic significance set forth.

In color the clays vary from the nearly white fire clays to brown, when they are rich in organic matter. These carbonaceous clays pass by all the degrees of graduation into lignite seams that are pure enough to be developed for fuel. Selenite, or crystalline gypsum, is found in the Laramie clays of all colors, but is particularly abundant in the brown layers. Crystals of considerable size occur and are commonly mistaken for mica. They are very rarely perfect in outline and their surfaces are commonly deeply etched. The brilliancy and variety in the coloring of the Laramie clays adds greatly to the beauty of many of the landscapes in the bad lands. Definite and sharply marked layers of orange, buff, brown, red and white clays alternate in pleasing variety. They are never fissile, most of them showing no tendency to split along lamination lines. Often they have a fat, oily feel and the tenacity of putty.

In certain layers plainly associated closely with the lignite, gastopod shells representing four species and at least one large pelecypod occur in great numbers. Specimens of these shells taken from the clay pit of the Mouse River Lignite Coal and Brick Company have been sent to the Smithsonian Institution for identification. A fossil bearing layer was found thirty miles north of Sentinel Butte, near the junction of the Beaver and Little Missouri. The vertical limit of the fossil horizon was four feet while its persistence laterally was considerable, extending over a number of square miles, as shown in the buttes in which the neighborhood abounds. The elevation of this fossil layer was considerably above that at Minot, and it is hardly possible that the two are continuous, though the fossil content, as to number and kinds of species and state of preservation, seems to be the same. Perfect specimens of the pelecypod were rare, while the gastropod shells could be obtained abundantly in great perfection.

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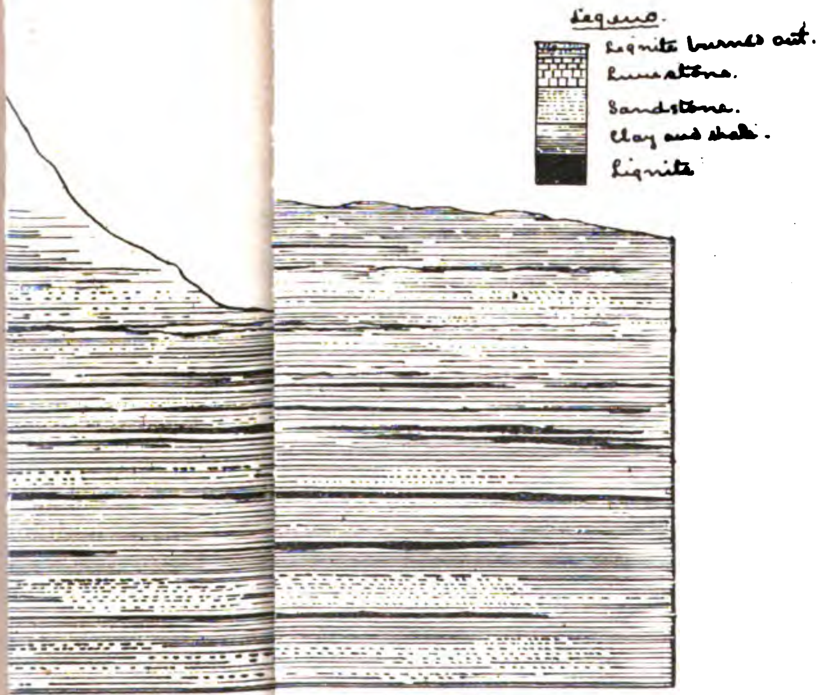
* Taken from First Biennial Report of Geological Survey of South Dakota. Analyses by Prof. E. J. Babcock.

Certain strata abound in silicified wood which preserves beautifully the original tree structure. Huge trunks three feet or more in diameter showing the annual rings, knots, and all the details of wood fibre though lacking the bark, are not uncommon. Near the Stone ranch, twenty-five miles north of Sentinel Butte, huge trunks twenty feet high, standing upright and evidently in the place where they grew, characterize a definite horizon in the clays. One of these stumps in which the wood structure is beautifully preserved though not brought out in the photograph, is shown in plate IV. Cavities in the silicified wood often contain clusters of minute quartz crystals. The fossilized wood is generally light colored, though often the presence of a considerable quantity of carbonaceous matter renders it dark. Specimens in which on the outside the wood has been silicified while within it has been changed to lignite are not uncommon.

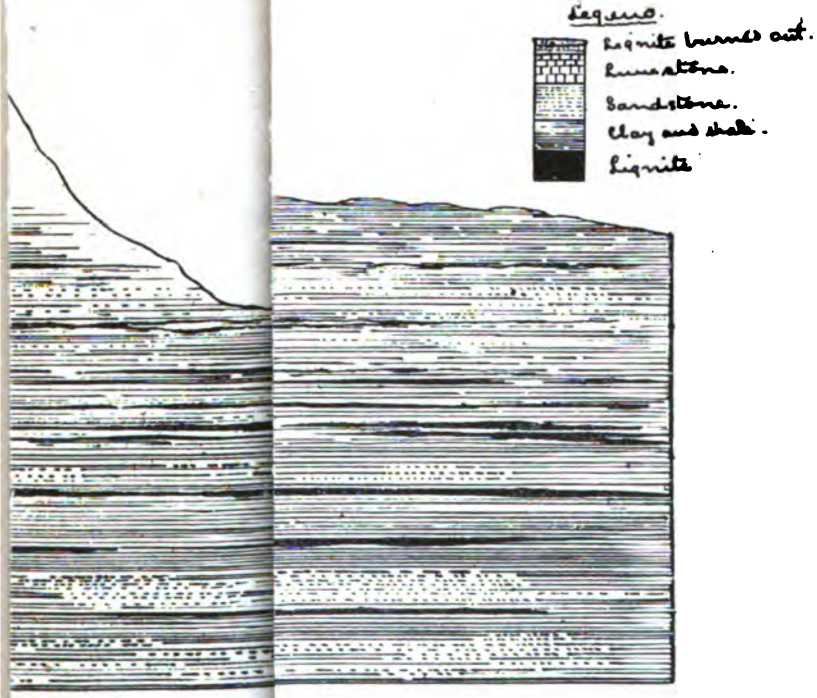
While the clay layers are for the most part horizontal, at times one or more layers will dip considerably and independently of those above and below them, the phenomenon appearing not unlike the cross bedding in sandstones. A single instance of this peculiar bedding is shown in figure 1. The strata here shown consist wholly of clays, differentiated by color.

The sand of the Laramie varies considerably, some of it being extremely fine and when saturated with water forming a quicksand, as shown at two of the mines near Minot and described in the accompanying report on Ward county.



AND SENTINEL BU

and is free from mica. The natural exposures show that rock presents great resistance to the weather, the great b ınying report on Ward county.



ND SENTINEL BU

and is free from mica. The natural exposures show that rock presents great resistance to the weather, the great blocks being but slightly eroded by wind or water and are very firm, when their long period of exposure is considered. Situated three miles from the railroad, with an abundance of good coal at hand, the quality and vast quantities of this sandstone would make it the most promising quarry proposition in the state, if shipping rates and a market were favorable. It is illustrated in place near the top of Sentinel Butte in plate V. Todd finds a similar sandstone at the top of the Laramie on the high buttes of the northwestern part of South Dakota.*

Sandstone nodules and concretions occur in great abundance in the sands and sandy clays of the Laramie. Their shapes are often grotesque, suggesting forms of plants and animals and they are frequently mistaken for fossils. They usually show plainly the concentric structure which reveals their origin. Many of them are remarkably round while others are elongated, all of the nodules in a given locality tending to take a common form. They are generally arranged in layers, a fair illustration of their mode of occurrence being given in the center of the frontispiece. Great disc-like bodies are not uncommon, the short axis of the disc being vertical, while the other axis may reach a length of twenty feet. Thin though very persistent bands of clay-ironstone partly oxidized to hematite occur frequently in the Laramie clays. The greatest thickness observed was two inches, the mineral at no point appearing in quantities of economic significance.

Limestone is equally rare, and when it does occur is highly argillaceous. The frontispiece shows a thin layer directly over the coal. Beautiful leaf prints are abundantly preserved in the ironstone layers.

The general characteristics of the lignite will be briefly described, detailed descriptions of exposures being reserved for the subsequent text.

NATURE OF THE LIGNITE DEPOSITS.

A careful consideration of the nature of the lignite deposits is important for practical and theoretic reasons. The numerous natural exposures of lignite in the driftless area and the remarkably fine opportunity to study the Laramie strata offered by the bad lands make it possible to draw, even from a preliminary study of the region, rather far reaching conclusions.

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*South Dakota Geological Survey, the First and Second Biennial Reports, with accompanying papers, pages 52-53.

A large collection of records from deep wells or prospect holes is needed to determine the nature and amount of lignite at considerable depth below the surface, but this is a deficiency which time will doubtless remedy.

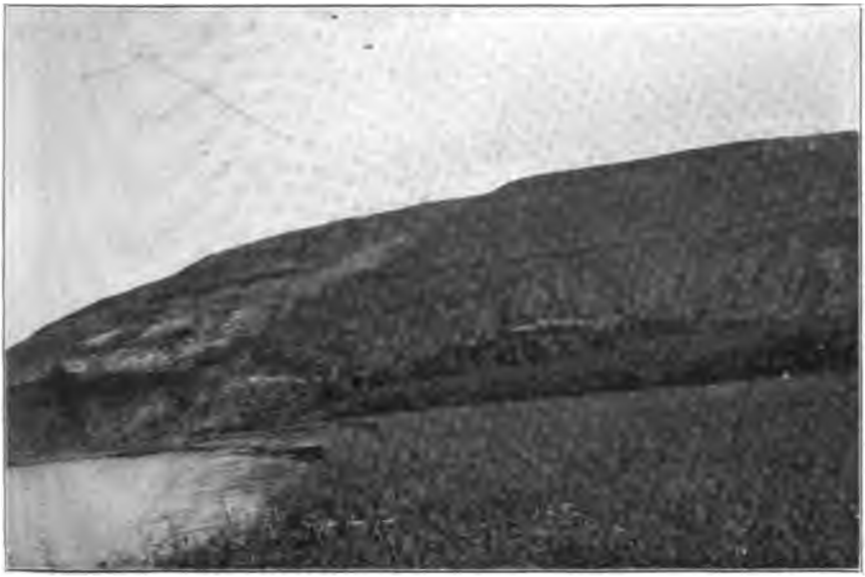
Number of the Seams.—A section in part ideal, through the Laramie strata in the western part of the state, given in plate VI illustrates the nature of the lignite seams and probably does not exaggerate their number in the region between Sentinel Butte on the west and Fryburg on the east. The five well developed seams shown in the sketch as outcropping in the bluffs of the Little Missouri actually exist and may be traced for miles north and south of Medora. The seams shown in Sentinel Butte are not imaginary, and it is highly probable that further search between the base of the butte and the top of the bluffs will reveal other seams. Along the Missouri river south of Williston five and six seams are easily traceable for long distances, while from the Berthold agency Mr. Wood reports nine well defined seams in a single exposure. These records are in part due to the excellent opportunity for observation given by the bluffs of streams in the driftless area where vertical sections of nearly two hundred feet are not uncommon. They are due also to the abundance of the seams. Near the eastern edge of the lignite area their number is greatly reduced, but even here two and three exist at certain points, though probably only one is workable. This portion of the area will be more minutely considered in Mr. Wood's report on Ward county.

On account of the nature of the seams, described in another paragraph, their number does not remain constant through large stretches of territory, and it is possible, though hardly probable, that in a few localities in the very heart of the lignite area a prospect hole passing completely through the Laramie would not encounter a lignite seam. This probable variation in number and thickness of seams often within comparatively short distances will be a factor of great practical importance in opening up on a large scale a new lignite field. In the first place it will largely increase the number of prospect holes which must be sunk to determine the amount of available coal in a given area. To offset this, however, are a number of conditions which make prospecting unusually easy.

Thickness of the Seams.—The lignite seams vary in thickness from an inch to forty feet. This maximum thickness, which was seen and measured during the past summer, outcrops in Township 135, Range 101, Section 31, and will be described in connection with the lignite of Billings county. On government land in Township 133, Range 104, Section 20, and in Sentinel Butte, three miles south of the town of the same name, are extensive seams twenty-five feet thick. Seams fifteen feet thick are not uncommon and are exposed frequently along the Little Missouri river and more rarely to the north and east. In the subsequent text a large number of seams between six and ten feet in thickness will be described. In the western part of the lignite area seams two feet or less were so abundant that in the preliminary work covered by the present report it was not practical to note them all minutely.

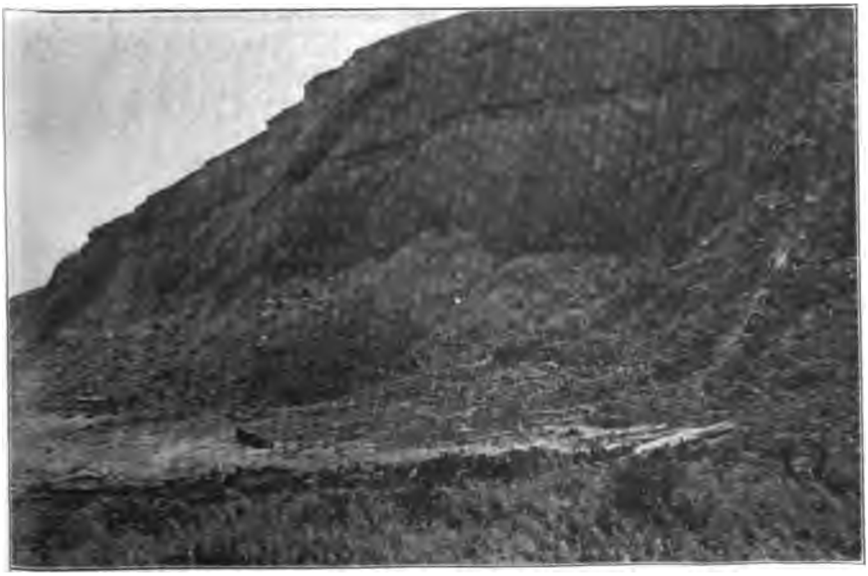
Extent of Seams.—As important from an economic point of view as their thickness is the extent, or persistence, of the seams laterally. The impression is somewhat prevalent that a single seam may be recognized at points separated from each other by a hundred or more miles. Special attention was directed to this point during the past summer, and the elevations of many of the coal seams in adjacent regions were noted in order to correlate the seams in one area with those of another, if this should be possible. Generally such a correlation was impossible on account of variations in thickness and elevation, unless a greater dip to the strata or more irregularity in the level of the surface on which the lignite was formed was supposed than actually seems to exist. If the nature of the seams admitted of such a correlation it would be very useful, for by prospecting along streams where natural exposures occur, it would often be impossible to determine the nature of the seams between two exposures widely separated. In some instances the lateral persistence of seams is considerable and can be demonstrated. In general, however, it was not found practical to correlate the seams in different exposures if the exposures were separated more than four or five miles. While a single seam was often traced for six miles or more along the banks of the Little Missouri, others seen at the same time thinned out and gave place to new ones a little above or below them. The interrupted seam often developed farther on after a break of perhaps half a mile, where the lignite was replaced by a bituminous, or even by a nearly pure clay. The deduction, which in the early part of the season's work seemed true, that certain horizons in the Laramie are notably richer in lignite than others, was not borne out by later

Plate VIIa



Bluffs on the Missouri, Three Miles Southeast of Williston, Showing Six Coal Seams.

Plate VIIb.



A Nearer View of the Above, Showing the Portion to the Left Only.

observations. For a given locality the statement holds good. The lignite about Medora, for instance, is present in thicker seams a few feet above water level than at greater elevations; but an elevation which abounds in lignite at one point may be barren in another. The accompanying sketch, plate VI, illustrates conditions as they seem to exist quite generally throughout the lignite area. The number of seams here shown is probably greater than that actually existing along the eastern edge of the area, but does not exaggerate their abundance in the west. A striking instance of the rapid thinning of a seam is given in the forty foot seam already cited, which within one-fourth of a mile shrinks to seventeen feet, the top and bottom of the seam drawing together like the surfaces of a lens.

Records of two deep wells, one at Medora, and the other at Dickinson, bored by the Northern Pacific Railroad, and quoted by Darton,* give an excellent idea of the frequency of lignite seams for a considerable distance below the surface of these points. The well at Medora, situated twenty-five feet above the waters of the Little Missouri, and 1,860 feet above sea level, penetrated the Laramie clay for 941 feet without passing through it. Seventeen lignite seams were encountered varying in thickness from a few inches to twenty-three and one-half feet, the total aggregating over sixty feet. Lignite was found but a few feet above the lowest point reached and is distributed nearly uniformly throughout the section. The Dickinson well in going from the surface at that point, 2,400 feet above sea level, to a depth equal to that of the Medora well, 819 feet above sea level, passed through a similar series. Sixteen seams were found, giving a total thickness of lignite of about fifty-five feet. The two points are thirty-nine miles apart, and in view of the data gathered this summer, Darton's attempt at correlation of the lignite seams appears doubtful. Figure 2 is a reproduction of his sketch.

Variations in Fuel Value of Lignite in the Same Seam.—Perhaps a majority of the lignite seams examined and tested by analyses showed no great difference in the fuel value of the lignite from top to bottom. In some instances, however, differences in the composition of the lignite in a given seam are noteworthy. Not infrequently the upper foot is inferior in quality and is left as a roof in mining. The loss in this case is not as

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*Preliminary Report on Artesian Waters of a portion of the Dakotas.

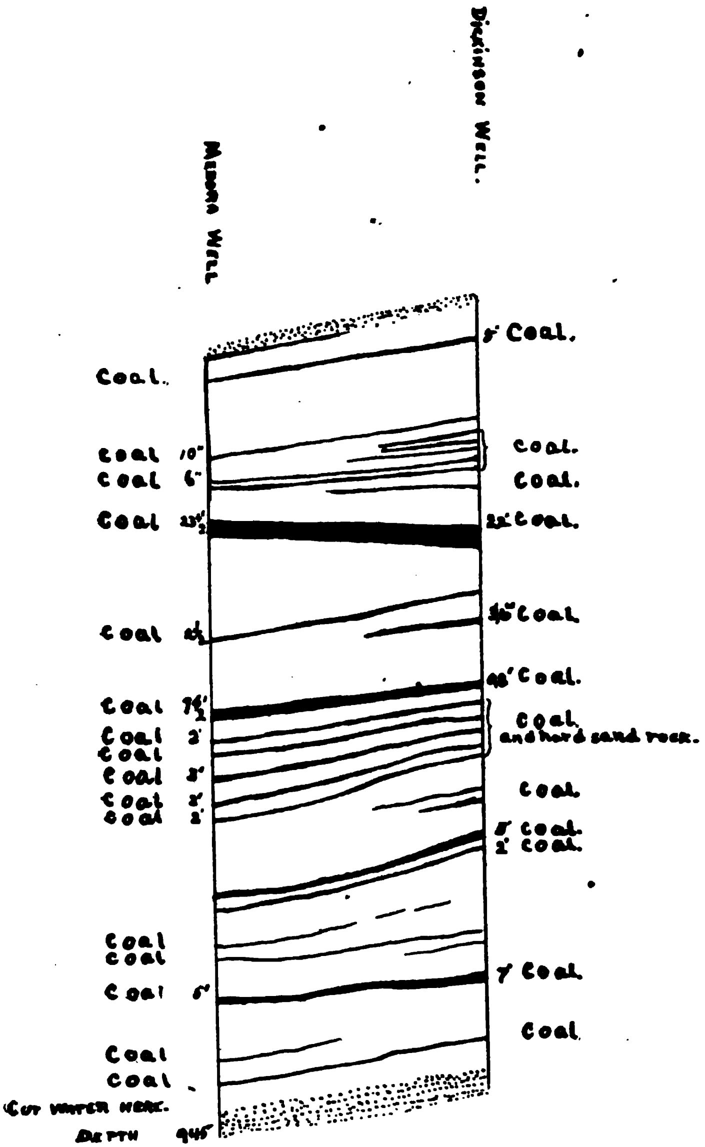


Fig. 2. Diagram of the lignite seams between Medora and Dickinson. After Darton.

great as might be imagined, for it is often necessary to leave coal to form a roof even though its quality is excellent.

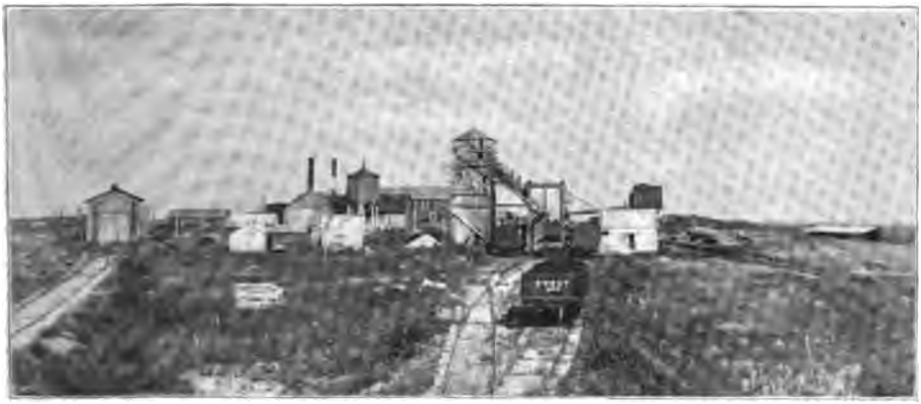
When the lignite lies directly under the glacial drift, as at the Hanchett mine ten miles south of Velva, the upper portion shows deterioration. Shaly layers sometimes occur, which, if mixed with the coal from the rest of the seam, bring up the percentage of ash for the whole very materially. Sulphur streaks are rare, the lignite generally being free from this objectionable element. In a number of analyses the highest amount was one per cent. Iron nodules, which prove so annoying to the operators of mining machines in the eastern coal, do not occur in the lignite, and there are no hindrances of this sort to the use of drills and under-cutting machinery. Pyrites of iron (Fe S) occur very sparingly, the yellow crystals occurring so seldom and appearing as such a novelty that not infrequently they are mistaken for gold.

Variations in Fuel Value of Different Seams.—The chemical analyses and calorimetric tests of fifty or more samples of lignite given in the latter chapters make clear the differences in the fuel value of lignite from as many parts of the state. Samples were not taken from seams that were obviously too thin or too impure to be of economic significance. While many of the thin seams show a high percentage of foreign matter, some of them, though only a few inches thick, seemed remarkably pure. The lignites taken as a whole will probably average somewhat better than the samples indicate, for in many cases perfectly fresh material could not be secured, and the weathering on the surface of a natural exposure is sufficient to lessen the carbon values for a number of feet back from the outcrop. As will be brought out in a later chapter, the lignites are generally of a very excellent quality, ranking according to the accepted standards for coal, between the ordinary lignites and bituminous coal.

Possibilities of Bituminous Coal at Greater Depth.—The generally accepted opinion that the lignites always improve in quality with depth is not wholly borne out by the facts. While it is true that seams poor in quality grow fewer as the depth increases, the lignite from some seams within sixty feet of the surface has a fuel value higher than that of other seams at a much greater depth. The deeper lignites have been exposed less to the action of ground water than have those near the surface, and have been subjected to slightly greater pressure, though the latter factor in this case is too small to be very significant. When an upper seam has been well protected by impervious clays from percolating water, and in its original constitution was as pure as the lower seams, it will probably equal them in quality. From above most of the upper seams from five hundred to a thousand feet of material have been removed by erosion, so that the two or three hundred feet of clays that are often regarded as an important factor in improving the quality of the coal are relatively insignificant. The analyses of the coals found in the deep borings made by the railroad companies in search of bituminous coal in the western part of the state are not at the disposal of the Survey, but the prospecting was undertaken some years ago, and since no developement work has been done the inference that bituminous coal in significant quantities was not found seems reasonable.

A Popular Fallacy in Connection with the Lignite.—The belief so often expressed that lignite seams outcropping on hillsides are certain to thicken as the mine goes back into the hill, is hard to account for except in the optimism which fortunately is the endowment of a large part of our race. While in many cases the seams doubtless thicken away from the outcrop, the converse will as often prove true. The coal seams being in general lens-like, it is impossible to determine whether the outcrops represent a section near the edge of the lens or across the center. In the former case the lignite will thicken as the drift goes into the hill till the center of the lens is reached, while in the latter it will become thinner.

"Burning Mines."—Evidence is at hand at nearly every point within the lignite area which shows that great quantities of this valuable fuel have been destroyed by fire. Thick masses of burned clay, red, brown, white, or vitrified to a dark glassy slag, cap many of the low buttes, or lie in confused heaps on the slopes. From Fryburg to Medora the Northern Pacific Railway passes through a region in which "scoria" as the burned clay is called, is particularly abundant. It makes an admirable railroad ballast, and would be of value for concrete work if it were near a large center of population. The burning of the lignite has probably taken place intermittently from the time when the upward movement of the earth's crust gave an incentive to the active erosion which cut down through the Laramie formations, exposing the lignite, until the present.



The Washburn Mine at Wilton.

Plate VIIIb.

Miners' Houses, Forming a New Town Near Wilton.

Beds that are still burning may be seen at a number of points in Billings county. Prairie fires and spontaneous combustion are probably responsible for the "burning mines" in both the present and the past. The burning of the lignite has directly affected the topography of the lignite area only in a very small measure, the real agent that gave rise to the buttes and the bad lands being the erosive action of water. Indirectly, by hardening the clay until it formed an effective protection for the softer underlying strata, the burning out of the lignite was a real factor in the problem of the origin of the bad lands.

Prospecting for Lignite.—Very frequently the lignite is fully exposed along freshly cut stream banks, and may be recognized at once. Where it has weathered for a long time it appears as a black clay and considerable digging is necessary to demonstrate its true character. In a grass covered region springs serve as the best indication of lignite. Perhaps four-fifths of the springs in the driftless area come out of lignite seams along coulees, where they are concealed by vegetation. Most of the wells obtain their water from the same source. Water, so obtained, is generally potable, and often very palatable. Vegetation is said to remain green longer in the fall along surfaces which conceal lignite seams, due doubtless to the abundant moisture.

In some cases masses of scoria may serve to indicate the presence of the lignite in higher elevations. The presence of lig nite in Sentinel Butte, for example, and of scoria on the top of the low buttes in the seven miles of territory that intervene between it and the Camel Hump and at the same elevation as the Sentinel Butte seam, render likely the existence of a portion of the same seam in the Camels Hump. In this case the supposition is that the lignite once occurred in the low buttes and in much of the intervening territory now reduced in level by erosion.

Origin of the Lignite.—The woody structure of much of the lignite is so obvious that it is hardly necessary to allude to its vegetable origin. A collection of fossil plants representing species that probably contributed largely to the lignite deposits of the state was made during the past summer and is now in the hands of specialists at the Smithsonian Institution, and the results of their determinations will be published in a later report. The generally accepted opinion is that the lignite represents accumulations of vegetable matter "in place," that is, in the locality in which the matter grew. Swamps more or less extensive, in which the water was sufficient to preserve the organic matter until large quantities had accumulated, formed most favorable sites for the future lignite beds. A subsequent change in the conditions, perhaps due to crustal movements, resulted in the deposition of fine sediment on the mass of fallen and matted vegetation, forming the overlying clay or sand layer. Deposits of this nature continued till the process of filling, perhaps aided by an upward crustal movement, raised the surface so that vegetation could again flourish, when the formation of a second lignite seam began.

This explanation has been fully developed, and is perhaps the most satisfactory that can be offered. It has long been accepted as an adequate explanation for most of the coal measures of Carboniferous age. The evidence that the Dakota lignites were formed in place, however, is not as strong as in the case of the eastern coal. While delicate leaf prints perfectly preserved are common in the clays, showing that they were buried in quiet waters, they are extremely rare in the lignite seams themselves. Stumps standing upright in the lignite with roots in the underlying clay were not observed in a single instance. The clay at the base of the lignite contains, at times, branches and leaves, but vegetable matter in any form is not more abundant than in clays in other positions. The clays associated with the lignite often show structures indicating current action rather than quiet water. More data must be gathered, however, before an alternative hypothesis can be satisfactorily elaborated.

The physical and chemical properties of the lignite will be more fully considered in the chapter on *the Fuel Value of the Lignites.*

REMNANTS OF STRATA YOUNGER THAN LARAMIE.

Over the top of Sentinel Butte large quantities of flint and chalcedony are scattered, in small fragments. Their occurrence at such an elevation and their manifest independence of the underlying Laramie sandstone arouses the interest even of those not given to the study of geology who climb to the top of the butte, and questions as to their origin are frequently asked. Most of the fragments are chipped showing a perfect conchoidal fracture. Their color on fresh fractures is a light gray. Occasionally fine moss agates are found among them. Their cherty origin is shown by their irregular surface when not artifically fractured, covered with limestone in which they were evidently formed.

Some fragments by their shape suggest that they are casts of branches or trunks of trees. No leaf or shell prints were observed. The top of the butte is level, with the exception of a mound forty feet high at its western end. The top and sides of this mound are bare and its composition throughout well shown. It consists of a very argillaceous limestone which breaks into thin, tough slabs. Fragments one-fourth of an inch thick containing three square feet of surface were easily taken out with a light pick. When tested with hydrochloric acid some layers readily and wholly dissolved, while others showed an insoluble, cherty center. No fossils were found, though a more careful search should be made before their absence is affirmed.

That the chert and the limestone of this mound are remnants of strata that once covered the butte is obvious. The age which is to be assigned to them is not so clear. Todd* has referred cherts and limestones of a similar nature, which occur on the top of the Cave Hills, and on Slim Butte just south of the North Dakota state line, to the White River group, on account of their resemblance to the Titanotherium and Oreodon beds on Sage creek and White river. On these buttes he reports the presence of "thin layers of fine grained, thin bedded, sonorous white limestone, in which are found numerous fossils of fresh water shells, including the genera Planorbis, Limnea and Physa. These are silicified, while the stone is largely calcareous. When subjected to acid it is found, however, that there is a bulky argillaceous residue which interferes with the easy solution of the rock."

The description, except for the fossils, answers very well for the limestone on Sentinel Butte. The same formation may be looked for on other high buttes of Billings and Stark counties.

THE GLACIAL DRIFT.

Over two-thirds of the lignite area glacial drift is present and exhibits a variety of interesting phenomena. The presence of drift of at least two glacial epochs has already been noted and the topography of the Wisconsin moraine has been briefly described. The characteristics of the drift of Ward county will be quite fully considered by Mr. Wood, and a brief description of the drift in other counties will be given in connection with an account of the lignite.

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*South Dakota Geological Survey, Vol. II, pp. 51 and 60.

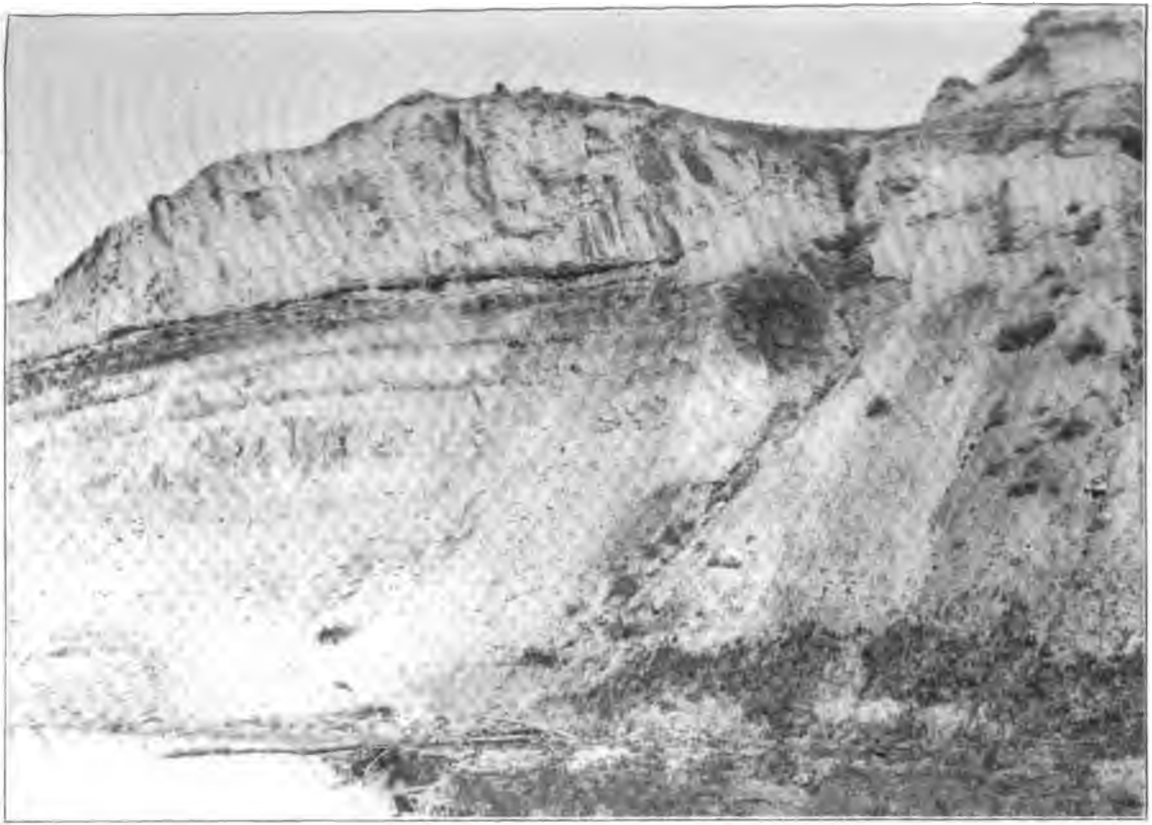
THE LIGNITE DEPOSITS OF WILLIAMS COUNTY AND VICINITY

FRANK A. WILDER.

The area here briefly described includes nearly three thousand five hundred square miles in the northwestern corner of the state. The Missouri river on its southern boundary greatly facilitates the study of the lignite deposits by exposures in its deep valley and along its steep bluffs; while Stony, Sandy and Muddy creeks have cut deeply into the Laramie clays, revealing through a considerable territory their fuel content. The country is covered with a thin layer of the older drift which is seldom a hindrance to prospecting. The topography of the country is, in the main, that of the older drift.

Lignite in the Vicinity of Williston.—The town of Williston is supplied with coal from seams which outcrop along the Missouri bluffs to the east, and in the valleys of Stony and Muddy creeks. The first or low bench of the Missouri is here two miles wide on the north side of the river, and from this the bluffs rise abruptly, and show a number of coal seams. At the Dahl mine, four miles east of Williston, in Township 154, Range 100, Section 28, considerable quantities of coal have been mined by stripping the overlying clay from one of the seams. Of late but little coal has been taken from this point, the amount of stripping required rendering the method unprofitable. The section shown in the bluffs at this point beginning at the top and going down, is as follows:

		FEET.	INCHES.
17.	Grass covered clays, to upland	40	..
16.	Clay	20	..
15.	Lignite	2	..
14.	Clay	20	..
13.	Lignite (the seam mined)	4	..
12.	Clay	50	..
11.	Lignite	..	6
10.	Clay	3	..
9.	Lignite	..	2
8.	Clay	6	..
7.	Clay ironstone	..	3
6.	Clay	3	..
5.	Lignite	..	3
4.	Clay	4	..
3.	Lignite	1	..
2.	Clay	4	..
1.	Lignite	..	6



An Eight-Foot Lignite Seam Near Medora, on the Little Missouri.

Lignite from the Dahl mine gave the following analysis:*

Volatile matter	42.65
Fixed carbon	52.78
Ash	4.57

Crazy Man's creek and Cedar coulee extend back from the river to the north, in this and adjoining sections, and along them lignite outcrops at a number of points. Three miles north of the Dahl mine in the bed of Crazy Man's creek is a spring which fills a three inch pipe with a strong stream of good drinking water rises out of a lignite seam, three feet of which are exposed. The lignite seems to be of good quality, though no mining has been done at this point. Its depth below the average prairie level is about that of the Dahl mine, and very possibly it represents the same seam. Observations made at many points within the lignite area, however, show that such a deduction is not safe. It may represent an entirely new seam, or by the rising of the seam become coincident with the upper seam, number 15, in the Dahl mine section.

In the adjacent Cedar coulee one of the finest lignite seams seen in the northern part of the state is exposed. It appears as the lowest number in the followng section:

		FEET.	INCHES.
18.	Glacial drift	10	..
17.	Lignite	..	6
16.	Clay	10	..
15.	Lignite	..	6
14.	Clay	10	..
13.	Lignite	..	4
12.	Clay	7	..
11.	Lignite	..	6
10.	Clay	7	..
9.	Lignite	3	..
8.	Clay	4	..
7.	Lignite, soft	2	..
6.	Sandy clay	15	..
5.	Clay	10	..
4.	Lignite	..	6
3.	Clay	9	..
2.	Sandy clay	35	..
1.	Lignite	12	..

The thick seam in number 1 of this section is excellent in quality. Considerable quantities have been mined by stripping, and preparations are being made to utilize it on a large scale.

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*Analysis by Prof. E. J. Babcock.

It is shown in the frontispiece with part of the overlying clay. The exposure of this seam is continuous for 3,000 feet near the bottom of the coulee, the amount of good coal demonstrated being very great. Its distance from the railroad is three miles.

Along Stony creek, between Avoca and Williston, lignite outcrops at a number of points. Three miles from Avoca is the old Taylor mine which for one year supplied fuel for Fort Buford. It is illustrated with overlying clays and thinner lignite seams, in figure 3, the formations illustrated being as follows:

	FEET.	INCHES.
7. Glacial drift	20	..
6. Lignite	1	..
5. Clay	20	..
4. Lignite	1	1½
3. Clay	10	..
2. Clay, very fine and firm	2	..
1. Lignite	5	7

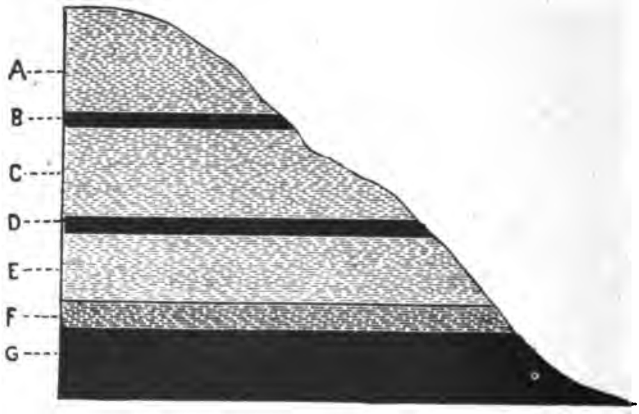

Fig. 3. Section from the old Taylor mine near Williston.

Analyses of two samples from this mine gave:

Number 1.	PER CENT.
Water and volatile matter, not dry	51.59
Fixed carbon	43.99
Ash	4.42
Sulphur	.17
Number 2.	
Water and volatile matter, not dry	52.23
Fixed carbon	43.76
Ash	4.01

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*First Biennial Report North Dakota Geological Survey, Prof. E. J. Babcock.

Along the creeks north of Williston a number of mines have been opened for local use, the coal being won by stripping. Among them are the Pettis mine on Red Bank creek, in Township 153, Range 102, Section 9, and the Cow creek mines, and the Metzgar mine. The seams worked are from four to six feet thick.

In central and northern Williams county, Mr. J. C. Field, county surveyor for Williams county, reports that lignite is very abundant, outcropping at a great many points along the coulees thirty or forty feet below the surface. This region abounds in springs which probably rise from the lignite. Their number in Township 156, Range 102, is said to be nearly sixty. In the central and western part of the county, in Township 158, Range 104, Sections 6 and 7, coal six feet thick is reported as outcropping continuously for 300 feet.

Three miles southwest of Williston, on the south side of the river, is a cut bank which shows a number of coal seams. The series given at this point is illustrated by the section:

		FEET.	INCHES.
17.	To upland	55	..
16.	Clay	4	..
15.	Lignite	2	..
14.	Clay	50	..
13.	Lignite	3	..
12.	Clay	5	..
11.	Lignite	1	..
10.	Clay	25	..
9.	Lignite	1	6
8.	Clay	8	..
7.	Lignite	..	8
6.	Clay	1	..
5.	Lignite	..	6
4.	Clay	25	..
3.	Lignite	3	..
2.	Sandy clay	2	..
1.	Lignite	3	..
	Water level.		

Plate VIIa shows seams 7, 9 and 11 of this section plainly; 5 is barely visible on the left. Plate VIIa shows the complete section; plate VIIb being a nearer view of the lower cut bank on the left. In addition to seams 7 and 9 of the section, the three foot seam number 13 is conspicuous, and above it, near the top of the bluff the two foot seam number 15 in the section appears. The lignite outcropping at the water edge is very solid, and makes excellent fuel. It persists along the river for some distance at this level, outcropping at the foot of the bluffs six miles up the river, where it has been mined by drifting into the bluffs, the entry extending 100 feet.

Across the river about Stroud, ten miles southeast of Williston, lignite is said to be abundant. At McArthur's sheep ranch on Red Wing creek, in Township 151, Range 100, ten miles south of Stroud, a seam from ten to sixteen feet thick is reported by Mr. J. S. Field as showing at nearly every bend in the creek for three miles.

The lignite about Hofflund, Grinnell and Nesson was studied by Mr. L. H. Wood, and the results of his investigations are given in connection with his report on Ward county and adjacent territory.

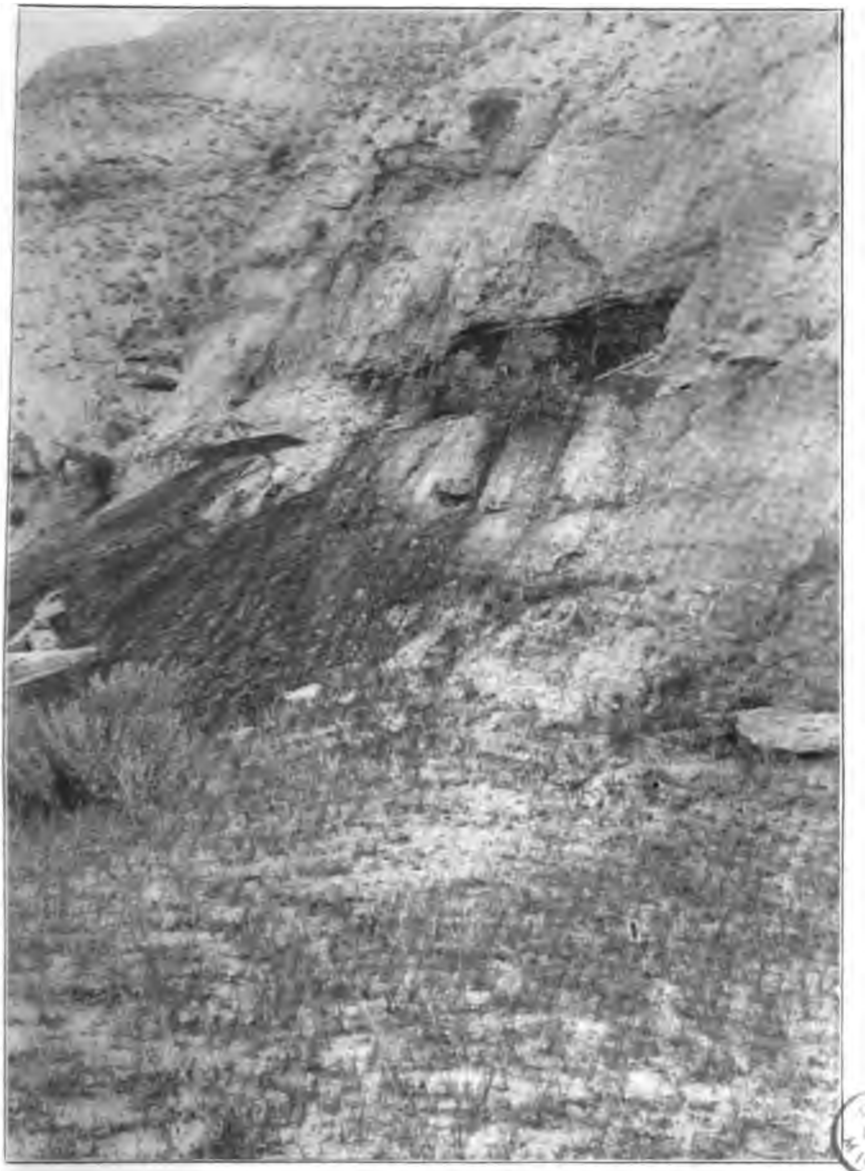
LIGNITE DEPOSITS OF BURLEIGH COUNTY

FRANK A. WILDER.

The Washburn Mine at Wilton.—Wilton is situated near the northern boundary of Burleigh county, in the center of an area stretching north into McLean county and across the Missouri river into Oliver and Mercer counties, which has long been known to abound in lignite coal. In reality this area is but a portion of the great lignite area, this being somewhat better known than the large region just west of it. Later study will doubtless show that western Oliver and Mercer counties are as richly endowed with lignite as the eastern portions along the Missouri river, and the section outlined above will appear as but a small fraction of the eastern edge of the great lignite area.

The coal about Wilton was first brought into special prominence by the opening of the large Washburn mine, the largest mine up to this time operated in the state. Work on a large scale in this region was rendered possible by the building of the Bismarck, Washburn & Great Falls Railroad, which developed a region with large mineral and agricultural resources. Although opened only two years ago, the Washburn mine would be regarded as a large mine, judged by the standards recognized in the older coal producing portions of the country.

The topography of the region about Wilton is that of the moderately rolling older drift. Drainage is complete and the surface conditions for farming admirable. At the Washburn



An Eight-Foot Coal Seam Two Miles North of Medora, Mined for Local Use.

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mine, which is a mile southeast of Wilton, the lignite lies sixty feet below the surface. No lignite is known to occur between the surface and the seam mined. In thickness this seam varies from eight to thirteen feet, the variations in thickness being irregular, and after being reduced to its minimum thickness it often thickens again. Variations of this sort are due to the rising of the floor or the lowering of the roof, or both. The base of the lignite dips consequently, not on account of folding in the strata, but because of unevenness of the floor on which it was deposited. Moreover it sometimes rises five degrees without any reduction in the thickness of the seam. Below the seam mined six to eighteen inches of clay occur, followed by a coal seam varying in thickness from six inches to two feet. The section, then, as given at the Washburn mine shaft is as follows:

		FEET.	INCHES.
5.	Drift	8	..
4.	Clay and sand	52	..
3.	Lignite	8-13	..
2.	Clay	..	6-18
1.	Lignite	..	6-24

Toward the west this vein grows thinner, and as shown by wells at Wilton, is there only two feet thick. Toward the north, however, it continues for seven or eight miles, its average thickness of eleven feet having been demonstrated in a considerable area by drilling. Whether the seam extends southeast continuously to the Ecklund mine, which is two miles away, is uncertain.

From six to eight feet of the seam are mined, the remainder being left to form a roof. Above the seam lie eight feet of brittle joint clay, which in turn is overlaid with sand. The mine is worked with the double entry and room and pillar systems, the width of the rooms being seventeen feet. A single row of wooden posts in the center of the rooms supports the roof. Between the rooms fourteen foot pillars are left. There is very little timber in the entries. While there is some water in the mine, the amount is not sufficient to render it troublesome. About 10,000 gallons are pumped every twenty-four hours. The flow in summer is somewhat stronger than in winter. The floor heaves slightly, due to the pinching in of the under clay, but the presence of the thin coal seam already noted as occurring two feet lower, greatly checks this tendency. Up to September, 1902, the lignite had been removed from about six acres.

The mine entry slopes from the surface at an angle of twenty-three degrees till the lignite is reached. At present six Jeffrey undercutting mining machines are in operation. After this machine is set it undercuts the lignite for a distance of seven feet in four minutes, the width of the groove being four feet. Electric drills are used, and six holes in two horizontal rows are drilled into the end of the room after the removal of the undercutter. Six shots are sufficient to bring down the lignite above the undercut, the lower row of three holes being shot first. For shooting, picking down and trimming rooms miners receive 30 cents a ton, and 35 cents for the same work in entries. Ventilation is secured by two thirty inch fans and one one hundred inch fan, the latter installed on the surface. The coal is brought to the surface in an elevator made by the Jeffreys Manufacturing Co., which hoists it from the level of the seam, sixty feet beneath the surface, to the top of a tipple from which it slides down chutes into cars on the sidetrack. An Ottumwa box car loader facilitates the process of filling cars. The surface equipment of the mine is shown in plate VIIIa, while b shows Chapin, the new town of miners' houses.

In August, 1902, the output was 180 tons a day, while during the preceding winter it reached 475 tons a day. During the present winter the daily output amounts to 1,000 tons.

The mine was laid out by Mr. R. M. Hazeltine of Ohio. mining expert. Mr. A. C. Dixon is superintendent, and C. P. Eckels manager. A diagram of the underground development appears in a subsequent chapter.

Two analyses of the Wilton lignite will serve to illustrate its excellent quality.

	PER CENT.
Number 1.	
Volatile matter	41.10
Fixed carbon	51.87
Ash	7.03
Number 2.	
Volatile matter	42.26
Fixed carbon	50.97
Ash	6.77

The Ecklund Mine is situated four miles southeast of Wilton, lignite occuring under conditions similar to those at the Washburn mine, and the probabilities are that the seam is the same. At present this mine is not in operation.

Analyses of samples are here given:*

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*Analyses by Prof. E. J. Babcock, First Biennial Report North Dakota Geological Survey.

Top Layer.	PER CENT.
Volatile matter	41.62
Fixed carbon	53.75
Ash	4.63
Center of Layer.	
Volatile matter	40.61
Fixed carbon	53.67
Ash	5.72
Bottom Layer.	
Volatile matter	42.41
Fixed carbon	50.47
Ash	7.12

The Charles Peterson Mine, five miles southeast of Wilton, in Township 142, Range 79, Section 9, was opened last fall. An entry about 100 feet long located on a hillside shows six feet of coal at nearly the same elevation as the Ecklund mine. Drilling farther back in the hill is said to have developed nine feet of good lignite. A considerable amount of fuel is being taken out of this mine for local use. It is worked on a basis of 10 cents a ton royalty under a five year contract.

Reports on a group of mines eight miles southwest of Wilton were obtained from a number of parties, though they were not personally visited. The O'Connor mine, in Township 142, Range 79, Section 30, is like the Peterson mine just described, and is operated under a royalty. The Jenks mine in the same neighborhood produces considerable coal yearly, four men being employed during the winter months. The O'Brien mine, one mile east of the O'Connor, is ordinarily a producer for local trade, but is reported as not in operation this year.

Other openings are reported in Burleigh county both east and west of Wilton. At the Casino mine, four miles southwest of Wilton, nine feet of lignite are said to occur.

These openings and natural exposures which probably are to be found within the county will furnish material for later investigation.

LIGNITE DEPOSITS OF BILLINGS COUNTY

FRANK A. WILDER.

The large area at present recognized as Billings county, with Medora as county seat, occupies the southwestern part of the state. It is crossed from north to south by the Little Missouri river, and is drained by its tributaries, the largest of these, Beaver creek, coming in from Montana. Many creeks of considerable size tributary to the Little Missouri exist within the county, though the number indicated on the ordinary map is not great.

Work in Billings county during the past summer was directed from four centers, and the total amount of time devoted to it was about three weeks. This was merely enough to emphasize the importance of the county in the study of the lignite problem. The bluffs of the Little Missouri were examined above and below Medora. Sentinel Butte was visited and the territory about the station of this name hastily gone over. Trips were made from the Stone ranch, twenty-four miles north of Sentinel Butte, and some idea obtained of the territory between Beaver creek and the Little Missouri, and of the nature of the valleys of these streams in this latitude. Going south from Sentinel Butte station the LeSueur ranch on Horse creek was the center of operations for a week. From this point the country for which Yule is approximately the geographical center was visited in many directions within a radius of ten miles. The report can most conveniently be made with reference to these four centers.

Lignite About Medora.—The casual traveler on the Northern Pacific Railroad has an opportunity to see something of the lignite deposits of Billings county from his car window. In the broken "bad lands" country on each side of the valley of the Little Missouri about Medora, but especially in the bluffs that here rise abruptly from the stream on the east bank, he can see numerous lignite exposures. At the last named point four seams show distinctly as black bands between the light colored clays. Of these seams the next to the lowest is shown in plate IX.

The complete section shown in the bluffs one mile north of Medora is given in figure 4. The section shown is as follows:

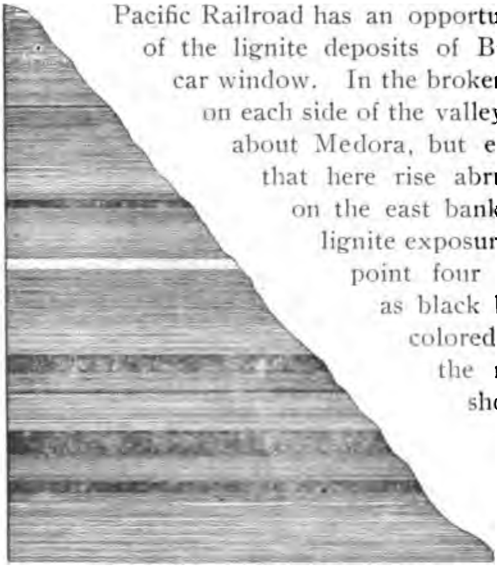


Fig. 4. A section showing the lignite seams in the bluffs at Medora.

		FEET	INCHES
17.	Clay	20	..
16.	Argillaceous sandstone	1	..
15.	Clay	20	..
14.	Lignite with much selenite	..	8
13.	Clay	40	..
12.	Lignite, good quality	3	..
11.	Clay	20	..
10.	Sandstone	5	..
9.	Clay	40	..
8.	Lignite, good quality	6	..
7.	Clay	8	..
6.	Calcareous shale	1	..
5.	Clay	17	..
4.	Lignite, good quality	8	..
3.	Clay	10	..
2.	Lignite	3	..
1.	Clay	27	..
	Water level.		

The lignite of number four is mined at a number of points on each side of the river about Medora. Plate X illustrates number eight of this section as it is mined for local use two miles above Medora on the right bank of the river.

One the west side of the river along the draw that is followed by the railroad lignite outcrops for three miles nearly continuously, three seams in the center of the section shown on the river coming close together till they are separated from each other by only six feet of clay. Lignite appears in the bottom of this draw three miles east of Sentinel Butte which possibly represents the highest of the thick seams found farther east. East of the river the situation is practicallly the same, seams showing frequently in the "breaks," and only detailed study will determine the extent to which they can be correlated with those outcropping on the river.

Both north and south of Medora lignite is abundant as at the points cited, and occurs under similar conditions, though the seams are probably not identical for any series of exposures separated more than four or five miles. At a number of points, as near Eaton's ranch, considerable quantities are mined and found satisfactory for fuel.

Coal in and about Sentinel Butte.—Situated three miles south of the station on the Northern Pacific railroad which bears this name is one of the most commanding buttes in Billings county. From the station to the butte the country gradually rises, the increase in the elevation becoming rapid within half a mile of its base. The aneroid shows that the top is 450 feet above the railroad, the last 200 feet of the ascent being a vigorous climb. A more complete description of this butte is given in the chapter on the Stratigraphy of the Lignite Area.

Near the base of the butte one of the largest lignite seams known in the state is exposed. Its thickness is twenty-five feet, and its continuance for a mile along the base of the butte was demonstrated. It probably underlies the entire butte, the base of which, at the horizon of the lignite, includes three or four square miles. At one point in Township 139, Range 104, Section 5, it has been mined to some extent. As here exposed in September, 1902, twenty feet of lignite were seen, and eight feet at the base were said to be concealed by wash that had accumulated since the bank was worked in the preceding winter. The upper five feet contained some sulphur, but aside from this the lignite seemed excellent in quality. The seam was free from concretions and clay streaks, presenting an unbroken wall of available fuel. The exposure at this bank last fall was 100 feet long, and the seam showed a slight dip toward the west. The lignite is won by stripping off ten feet of sandy clay that here overlie it; but as the butte rises rather sharply above it, the amount of stripping required will soon render this method unpractical. One-fourth of a mile farther west, in a small ravine that cuts into the side of the butte, the same seam, is exposed, showing a complete section and demonstrating that its thickness at that point is twenty-five feet. The quality, as at the other exposure, seemed excellent. A large amount of lignite can be secured here with very little stripping. An analysis of the lignite from this seam taken from the point where it is now mined is given below. It represents an average of the entire seam, the upper sulphur bearing layer included the material being taken from five points at different elevations and thoroughly mixed. Fuel from this seam is used in the town of Sentinel Butte and neighboring ranches, and is highly esteemed. One hundred feet higher in the butte a four-foot seam of lignite outcrops at a number of points on the north side and at least one point a mile away on the west end of the butte. The lignite from this seam as now exposed is soft, but quite probably the quality will materially improve as the stripping continues and the weathered portion is removed. It has been used to some extent locally.

Both of these seams are shown in position in the sketch giving the cross section from Sentinel Butte to Fryburg, plate VI. The large seam is shown in plate XI.

Lower seams of lignite doubtless exist in this locality, though little deep drilling has been done to bring them to light. At the Gilbert ranch, one-fourth of a mile north of Sentinel Butte station, lignite of an unknown thickness, found in digging a well, is reported forty feet below the station level and sixty feet beneath the surface. The well ended in the lignite, and good water being secured, no effort was made to go through it. The Gilbert coal bank, a little to the east of Sentinel Butte station on the north side of the track, in Township 140, Range 104, Section 21, shows a four-foot seam a little below the railroad track.

Lignite in the Vicinity of the Stone Ranch, Twenty-five Miles North of Sentinel Butte.—The surface of the country between Sentinel Butte and the Stone ranch is strongly rolling, and at times rough. The Camel's Hump, a high butte, is the most conspicuous elevation, while the "low buttes," usually capped with scoria, are very abundant.

Fifteen miles north of Sentinel Butte, on the road to the Stone Ranch, in a cut bank by a small creek, the following section was seen:

		FEET	INCHES
11.	Clay	6	..
10.	Lignite	1	..
9.	Clay	6	..
8.	Lignite	..	6
7.	Sand	12	..
6.	Lignite	4	6
5.	Clay	1	..
4.	Lignite	1	6
3.	Clay	..	6
2.	Lignite	..	6
1.	Clay	6	..
	Water level.		

A more thorough search will doubtless reveal many such natural exposures in the region, and some of them may be expected to show thicker lignite seams. Along the creek near which this section was taken, lignite outcropped at a number of points, and furnished fuel for adjoining ranches; although no analyses from samples taken at this point were made, the quality of the coal seemed good.

About the Stone ranch the surface is decidedly broken and good opportunities were given to study Laramie clays. Many deductions stated in the chapter on Stratigraphy were based on observations made at this point. Sand layers are unusually abundant, locally hardened to form a durable sandstone. The fossil stumps found at this point have been described and are illustrated in plate IV. Lignite was not very abundant in this immediate vicinity, though the seams exposed increased toward the east and west in the vicinity of the Little Missouri and Beaver creek. At the Stone ranch lignite, rather inferior in quality, is obtained in a three-foot seam, outcropping near the top of the buttes. Although the Laramie clays for a hundred feet below this seam are exposed, no lignite appears in them.

The coulee in which Roosevelt creek flows heads near this point and continues east into the Little Missouri. Like many of the creeks in Billings county, it is reworking an older wash-filled coulee and only here and there is attacking the Laramie clays. This point must be kept in mind in the prospecting for coal at most points in Billings county. The difference between the wash and the Laramie clays in places is so marked that when the attention has once been called to it, there is no danger of confusion. Figure 5 illustrates conditions as they exist on Roosevelt creek and at other points in Billings county both north and south of the Northern Pacific railroad. This figure shows a broad valley between two round topped buttes, composed of Laramie clays and lignite, filled with wash from their slopes. The creek at present is shown as excavating one side of this valley and cutting into a lignite seam below, while above the lignite is concealed by the wash. Within a short time the undercutting of the seam at this point would probably bring down

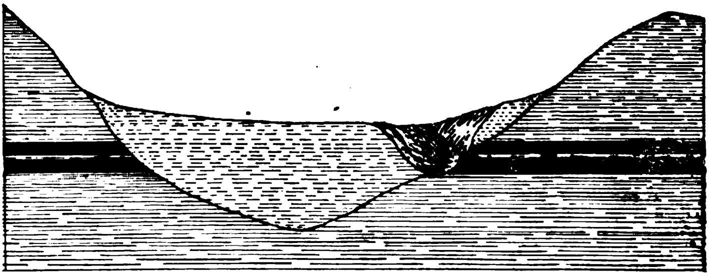


Fig. 5. Diagram showing a valley filled with wash which is being recut, exposing lignite seams.

the material above and reveal both seams. In many instances the apparent rapid thinning of a seam can be accounted for in this way. On Roosevelt creek, a seam two feet and a half thick is repeatedly exposed and concealed in this manner. Plate XII illustrates the reworking of an old wash filled hollow, giving an example of the phenomena generalized in figure 5.

Thick seams of lignite are reported in the banks of the Little Missouri just east of the Stone ranch, and about Mikkelson and to the west of Beaver creek. Part of the work of the Survey, as outlined for next summer, will consist of the verification of these reports, and a study of the river terraces at these and other points with reference to irrigation.

Lignite About Yule.—An area including nine townships will be briefly considered under this title. Its topography is diversified, including the Little Missouri valley and its terraces, the "breaks" in the vicinity of the river, and the rolling country on either side of the river, most of which is too open to furnish protection for stock in winter, but provides an unequalled summer range. On account of these conditions summer ranches are established in the comparatively open country where half a township is as level as a prairie, while in winter the ranch is moved to the "breaks," which furnish protection against the driving storms. Prospecting for coal is carried on more readily of course in the breaks, but on the prairie-like stretches seams often lie so near the surface that the prairie dogs bring fragments to the surface, so that in two instances seams were located in this way; and very light stream cutting was sufficient to show workable seams. Ranch men away from the Little Missouri seldom find it necessary to go far for fuel. Many of them consider it easier to go to the river in winter, however, and driving on the ice to break up the great lignite blocks which the stream has washed out. More than half of the area had not been surveyed in September, 1902, and it is impossible to cite locations definitely in many cases.

In Range 105, and Townships from 133 to 138, which includes an area near the state line from twenty to forty miles south of the Northern Pacific railroad, a number of coulees head, in which creeks flow eastward, uniting with the Little Missouri river. In going from north to south, Williams, Garner, Bull Run, Horse, Coal Canyon, Cannon Ball, Boise and Bacon creeks are crossed in about the order named. All of them show lignite more or less continuously from the time that they first cut through the sod till they empty into the Little Missouri, their courses varying in length from ten to twenty miles. None of these creeks, except Cannon Ball, is shown on the map.

Lignite on Williams Creek.—The lower portion of Williams creek was not visited, though lignite is reported as showing abundantly along this portion of its course. Beginning six miles from its mouth, the stream was followed west for two miles and a number of good exposures were examined. At this point its bed is approximately 200 feet above the water of the Little Missouri. The section shown in the cut banks was as follows:

	FEET	INCHES
5. Lignite, fair	2	..
4. Clay	20	..
3. Lignite, good	4	..
2. Clay	4	..
1. Lignite, thickness not known, one foot exposed.		
Water level.		

The lignite seams dip toward the east, rising toward the west somewhat faster than the creek, or some thirty or forty feet per mile. These seams were traced by a series of nearly continuous outcrops for almost a mile along Williams creek, and for a considerable distance along one of its tributaries, their thickness and quality remaining constant.

Lignite on Garner Creek.—Some lignite is exposed on this creek, though not as much as along those adjacent. Good springs are common in its upper course, and a little digging will probably reveal the lignite seams from which they come. On a branch of Garner creek, which unites with the main stream eight miles west of the Little Missouri, a four-foot seam is said to outcrop.

Lignite on Horse Creek.—Along Horse creek for more than six miles lignite seams varying in thickness from three to six feet are exposed at various elevations.

Near the Stewart ranch six feet of coal, four of it excellent in quality, are mined in a draw thirty feet below the top of the divide which here separates the waters of the Little Missouri from those of Beaver creek.

Lignite on Coal Canyon.—An abundance of lignite is exposed along the deep ravine that bears this name. The seams were examined and measured at a number of points from one to three miles west of the river. The section there given was:

		FEET	INCHES
6.	Lignite, fair	5	..
5.	Clay	1	3
4.	Lignite, good	7	..
3.	Clay	1	..
2.	Lignite, good	1	..
1.	Clay	10	..
	Creek bottom.		

The lignite at this point is shown in plate XIII.

An analysis of dried material taken from a number of points in the seven-foot seam shows:

Volatile matter	38.57
Fixed carbon	52.47
Ash	8.96
	100.00

The lignite in Coal Canyon at this point is approximately on a level with the upper thick seam which will be described as outcropping in the bluffs of the Little Missouri, a mile and a half to the east.

Lignite on Cañnon Ball Creek.—This creek empties into the Little Missouri about twenty-five miles south of Medora, and is a stream of some importance, its valley a mile from the mouth being nearly a mile wide.

Six feet of good lignite outcrop at this point in its course, two feet above low water level, and the stratum was traced continuously for 100 feet, till it was concealed by alluvium. Along the Little Missouri and in all the ravines in this vicinity, four and five seams of lignite are exposed, usually at an elevation much higher than that of the seam just noted. Well up in the buttes is a five-foot seam, plainly burned out over a large area, remnants only remaining here and there. While all about are masses of burned clay, there is none over the areas where the lignite is intact.

Lignite on Boise Creek.—The outcrops seen here were of thin seams only, though the lower part of the valley where they are usually more abundant was not visited. Some miles above the mouth two and three seams, each two or three feet thick, were occasionally exposed.

Lignite on Bacon Creek.—At the J. C. Gamel ranch in Township 133, Range 104, Section 20, a very thick seam outcrops and is mined by stripping for use in the neighborhood. The elevation of this lignite is considerable, only seventy-five feet less than the average level of the surrounding country. The thickness of the seam, as determined by measurements made at this point, is twenty-four feet. As now exposed it does not appear to be of the best quality, though surface weathering may be offered in part or wholly in explanation of its apparent inferiority. An analysis of dried samples taken from the surface shows:

Volatile matter	37.59
Fixed carbon	55.90
Ash	6.51

This seam is illustrated in plate XIV. Other seams are said to be exposed in the banks between this point and the Little Missouri river.

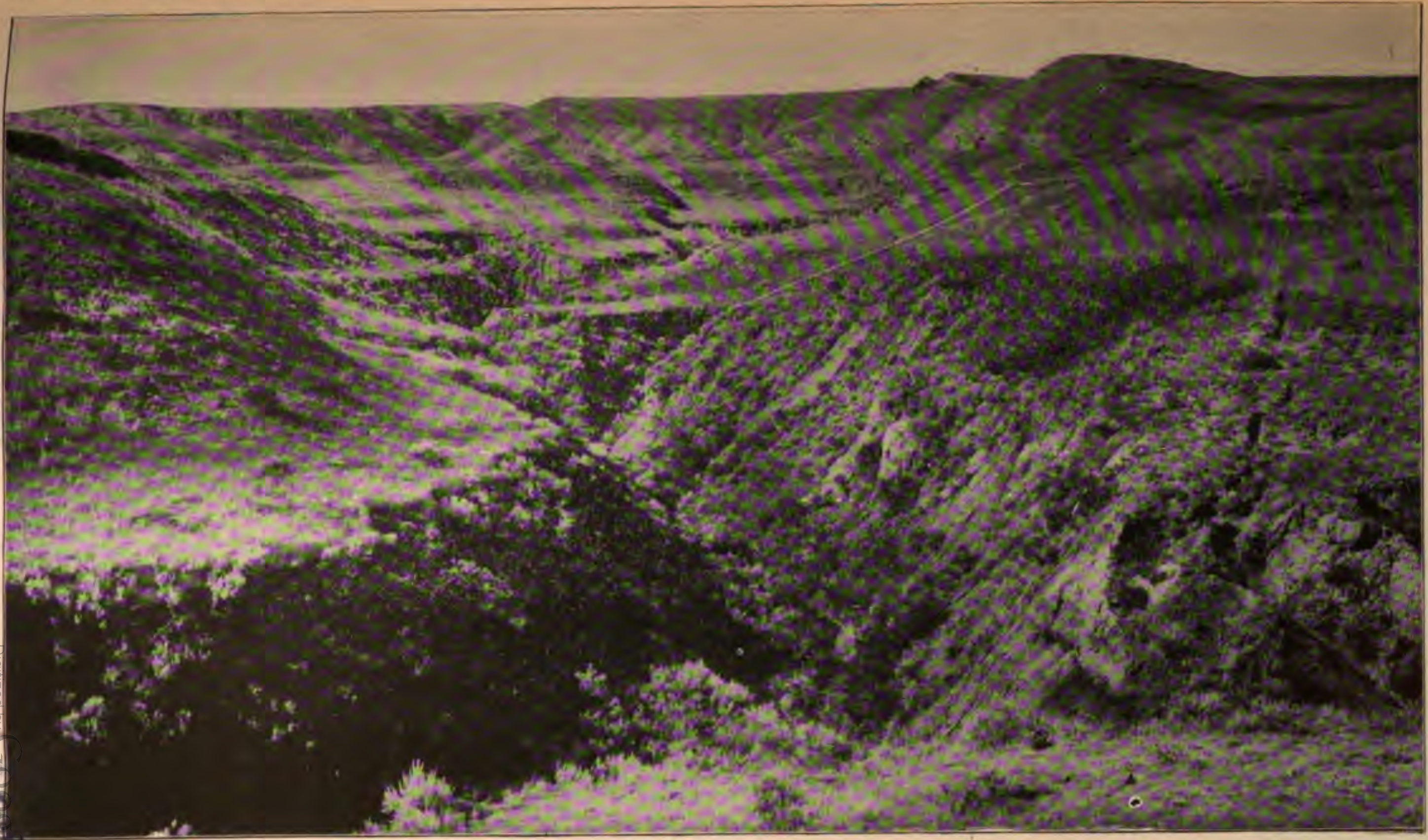
Lignite on Sand Creek.—Reports of a lignite seam forty or more feet thick, which was said to occur thirty miles southwest of Dickinson and about an equal distance from Medora, directed attention to the country east of the Little Missouri. Directions for finding the "big seam" were somewhat vague, but that it was located on Sand creek at length became certain. When found, it proved to be near A. E. Russel's ranch, and in Township 135, Range 101, Section 31, on land that the surveying party, which had just passed through, had determined to belong to the Northern Pacific railroad. Lignite outcrops continuously for a quarter of a mile along the creek. At the north end of the exposure the section given was:

	FEET	INCHES
6. Sandstone	2	..
5. Clay	10	..
4. Lignite	2	..
3. Clay	2	..
2. Lignite	15	..
1. Clay	3	..
Water level		

At the south end the lignite reached the remarkable thickness shown below:

	FEET	INCHES
Clay	5	..
Lignite	3	..
Clay	2	..
Lignite	40	..
Water level		

How far this thickness is maintained could not be determined, for, while the outcrop was traced south of the point at which the last section was taken, conditions for measuring the total thickness were not favorable. The rapid thinning of the seam to



A Gulch in the Bad Lands Which Is Being Cut Rapidly in the Wash That Has Filled an Older Gulch.
Photo by Rev. H. V. Rominger.

the north furnishes a most effective illustration of the nature of many of the lignite beds.

The lignite throughout the seam appeared to be of good quality, with the exception of the upper two feet, which were rather soft. An analysis of dried material taken from four points at different elevations in the south end of the exposure gave the following results:

Ash	37.59
Volatile matter	55.90
Fixed carbon	6.51
	100.00

In one small area the seam is wholly burned out. On account of its position, great quantities of lignite can be obtained with very little stripping.

Lignite on the Little Missouri Near the 7 7 7 Ranch.—Some very fine lignite seams outcrop at this point, which is some miles south of Yule. Rising directly from the water's edge at one point, the banks of Laramie clay and coal reach a height of 110 feet, which is the level of the second terrace, shown in figure 13. In the hills back of this terrace the surfaces are concealed and a section in height equal to that at Medora could not be obtained. Lignite seams probably exist above those noted. The section shown was as follows:

		FEET	INCHES
8.	Clay	20	..
7.	Lignite	3	..
6.	Clay	10	..
5.	Lignite, soft	3	..
4.	Clay	18	..
3.	Lignite, good	5	..
2.	Clay	30	..
1.	Lignite, good, more than	12	..
	Water level.		

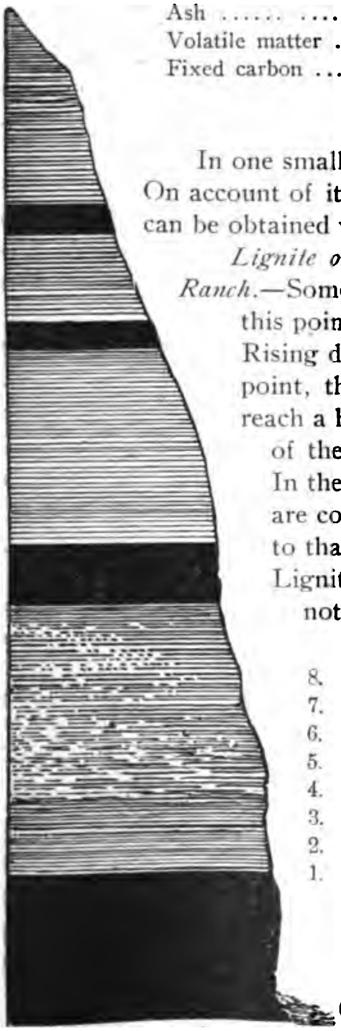


Fig. 6. Section thirty miles south of Medora at the 7 7 7 ranch, showing lignite seams.

This section is illustrated in figure 6. The lowest seam extended below water level, and its thickness could not be determined. It is shown in plate XV, where it extends from the water to the end of the hammer above the climber without a break. The other seams in the section are barely shown in the distant bluffs. The lignite from the lower seam is highly esteemed by the neighboring ranches, and appears to be unusually firm. An analysis of dried material taken from a somewhat weathered surface gave the following result :

Volatile matter	34.55
Fixed carbon	43.47
Ash	21.98
	100.00

Lignite at Yule.—Two and three seams are exposed in the bank of the Little Missouri both north and south of Yule, one of them of good quality. The lower seam found farther up the river and described in the preceding paragraph was not seen, but conditions were not favorable for an outcrop close to the water.

Lignite in Black Butte.—This imposing butte, probably equal in elevation to Sentinel butte, is situated not far from Township 134, Range 101, about forty miles south of Medora. Like Sentinel butte it is capped with a heavy sandstone stratum. Two lignite seams are reported as outcropping in its sides, one of them, said to be six feet thick, being mined to some extent.

At the Gamble ranch, three miles west of the butte, a fine spring was seen flowing from a lignite seam, the thickness of which was not known. The quality of the coal appeared good, and it was but a short distance beneath the surface.

LIGNITE OF McLEAN COUNTY

F. A. WILDER AND L. H. WOOD

For convenience in description, the lignite of McLean county will be reported in connection with six centers: Coal Harbor, Fort Stevenson, Coal lake, Washburn, Dogden Butte and Harvey. All of these centers were visited during the past summer, the last two by Mr. L. H. Wood, who has described them for this report. Lignite is by no means restricted to these centers, but development work has been carried on about them to some extent, and data could be obtained without too great an outlay of time. The county will well repay more exhaustive study.

Lignite About Coal Harbor.—Coal Harbor is situated in the western part of the county, near the Missouri river. The lignite deposits in its vicinity have long been known, and early attempts were made to exploit them. Naturally the first exposures recognized were those along the Missouri river. In the bluffs near Coal Harbor, the following section occurs:

	FEET	INCHES
Clay	70	..
Lignite	6	..
Clay	80	..
Lignite	4	..
Clay	1	..
Lignite	7	..

The lowest seam is 220 feet below prairie level, and thirty feet above the water of the river.

Lignite outcrops also along two creeks in this vicinity. In Township 147, Range 84, Section 24, in a coulee forty-five feet below the upland level, a lignite seam was visited, said to be eleven feet thick, though but seven feet could be seen at the time, the lower portion of the seam being covered with recent wash. As now exposed the lignite is covered directly by glacial drift, though Laramie clays will doubtless appear above it as the stripping is carried farther back into the bank. A twelve-inch clay seam occurs in the middle of the lignite. A small spring flows from its base. This seam is illustrated in plate XVI.

As reported by Mr. Geo. R. Robinson, of Coal Harbor, eight and one-half feet of lignite at a depth of 108 feet were passed through in digging a well on Township 146, Range 83, Section 6; while on the same section, and starting from practically the same upland level, a well reaching a depth of 126 feet encountered no lignite. While the lignite beds often diminish in thickness rapidly, it does not seem probable that a seam of this size would thin out so quickly. In the report given of the occurrence the glacial drift and Laramie clays were not distinguished; and the phenomenon may be explained by preglacial erosion. In Township 147, Range 83, Section 30, seven feet of lignite are reported as occurring in a well sixty-eight feet below the surface.

Lignite About Fort Stevenson.—For many years lignite was mined on the old Fort Stevenson reservation for use at the fort and the Indian school formerly located there. The exact location of the mine was in Township 148, Range 85, Section 35, southwest one-half. A seam said to be fourteen feet thick was mined by stripping. When seen last summer, the lower part of the excavation had filled in and only the upper two feet of lignite were visible. This mine is situated back of the broad, low terrace of the Missouri river, and about thirty feet above it. Higher up in the bluffs other lignite seams occasionally outcrop, the best exposures seen occurring half a mile east of the Fort Stevenson mine. The section here given was:

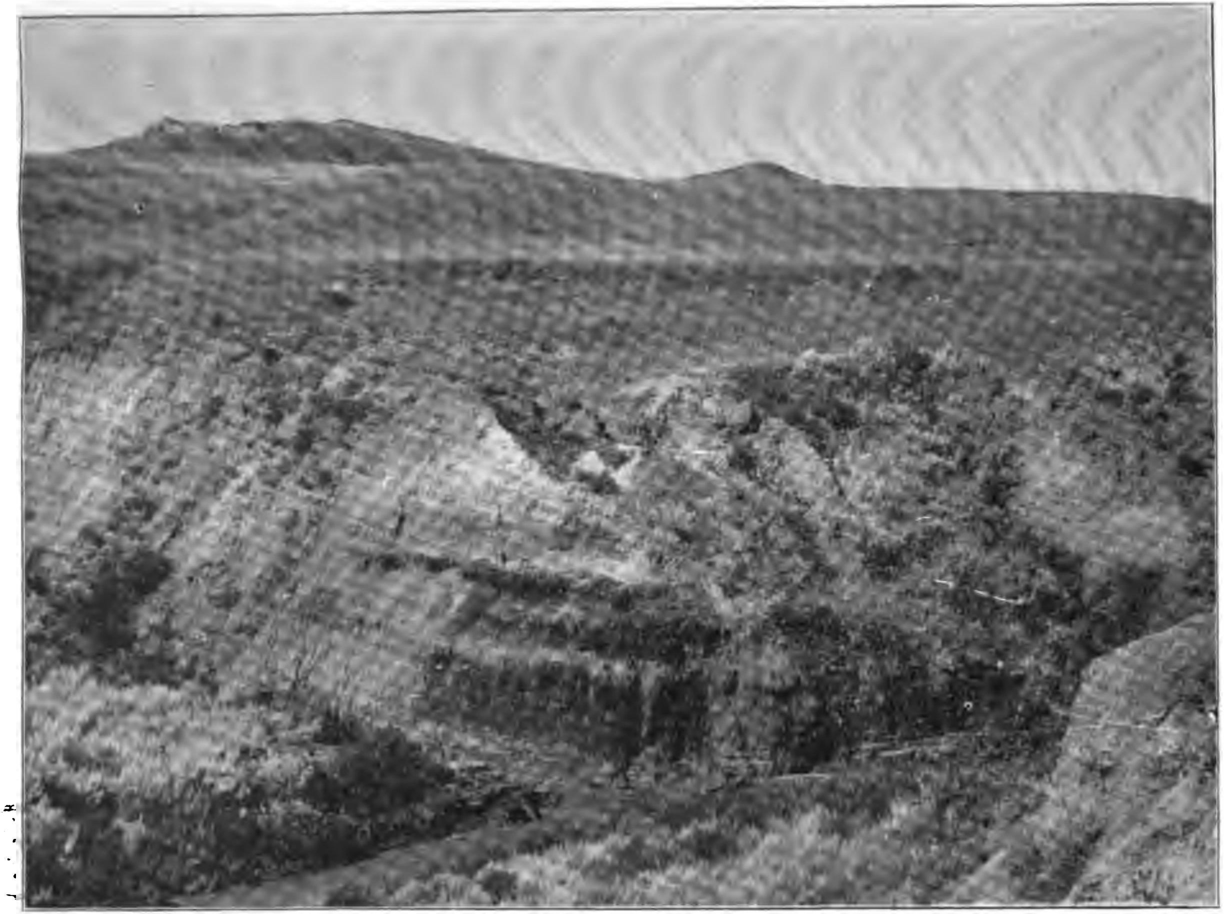
	FEET	INCHES
5. Lignite	1	..
4. Clay	1	..
3. Lignite	1	..
2. Clay	1	..
1. Lignite	6	..

The seam worked at the Fort Stevenson mine may be found twenty or thirty feet below the lowest number of this series.

Springs of considerable size issue from the lignite at the Fort Stevenson mine. Conditions for drainage, however, are good, the seam lying considerably above the river flat.

Lignite About Coal Lake.—There are large quantities of lignite exposed along Coal lake, formerly known as Buffalo lake, and the creek that drains it. Exposures are common in Townships 145 and 146, Ranges 80 and 81. Turtle creek was followed north from Washburn, and along its banks a number of exposures were seen. The seams generally reached a thickness of five feet. Throughout the valley the lignite is accompanied by springs, some of them of considerable size. In Township 145, Range 80, Section 29, a seam more than six feet thick was seen, the lower four feet apparently of good quality, while the top was soft. Considerable lignite is obtained from this point by stripping, the output last year being about 1,000 tons. The outcrop is about seventy-five feet below the upland level. In Township 146, Range 81, Section 13, on the east side of Coal lake, a new bank has been opened, showing three or four feet of coal. One-half mile further down the coulee on which this seam occurs is the "Little Coal Lake" mine. Though no coal could be seen where the bank was visited, a large amount of work had evidently been done during the preceding winter. The amount of stripping now necessary is twenty-five feet, and further development can best be carried on by drifting.

The amount of lignite exposed at the Coal Lake mine, in Township 146, Range 82, Sections 22 and 23, when visited in September, 1902, was nine feet. The lower portion of the seam was plainly concealed by wash from the slope, and the reported thickness of fifteen feet doubtless exists. The upper two feet are very



A Ten-Foot Lignite Seam on Coal Canyon. The Photograph Shows Nicely the Topography of the Country a Few Miles Back From the Little Missouri, Thirty Miles South of Medora.

soft, but the lower coal seems good. The seam is probably the same as that shown in the "Little Coal Lake" bank. It is exposed along Buffalo creek for half a mile.

The Satterlund Mine Near Washburn.—This mine, situated six miles northwest of Washburn, has for a number of years supplied a considerable portion of the fuel used in that town. The lignite obtained from it is esteemed very highly on account of its excellent quality. It is situated on a coulee which leads to the Missouri river, the lignite occurring well down on the slope. Directly over the coal is twenty feet of sand, locally hardened to sandstone. The seam is ten feet thick, the lower eight feet excellent in quality, while the upper portion is soft and left for roof. The coal is obtained by drifting into the side of the coulee, the entry at present extending back 200 feet. While there is some water in the mine, the amount is not sufficient to lessen the value of the property from a mining standpoint. Analysis of this lignite shows:

	PER CENT
Volatile matter	37.50
Fixed carbon	55.89
Ash	6.61
	100.00
Moisture	30.91

During the present winter the mine is being operated in a small way on a royalty.

Lignite in the Vicinity of Harvey.—Harvey is situated a few miles east of the divide which separates the tributaries of the Mouse from the Sheyenne and the James that flow to the southeast. In this position the town lies to the east of the known workable seams. Harvey and the other prosperous towns along the Soo in Wells county are just near enough to valuable lignite seams on the north and west to realize the value of such seams to the community that is fortunate enough to possess them. With a view to finding lignite near Harvey, if any exists, considerable prospecting has been done, and a responsible party who had a contract for part of the work reports that prospect holes were sunk both above and below Harvey on the Sheyenne river as far as the Pony Gulch mine. The result of this enterprise showed that a seam only a few inches in thickness underlies the banks of the river at a depth of forty feet. Careful search has been made for signs of lignite in other parts of the county. Mr. Sykes, who has lived at Sykeston for twenty years, reports that he has not discovered lignite in any of the wells dug between Sykeston and Boden; and, furthermore, that the supply of lignite for the village had for years previous to the opening of the Washburn mines, been hauled from the Pony Gulch mine, some thirty miles away

Inasumch as Wells county contains the sources of three streams—the Sheyenne, the James and the Pipestem—all of which rise at about the 1,600 level and flow eastward through a region where the drift is often thin, opportunities for lignite exposures are good if it exists in this vicinity. No outcrops, however, have yet been reported: At present, so far as the lignite is furnished by local mines, the county can be said to depend for its supply upon the Pony Gulch mine, situated in Township 148, Range 74, just over the McLean county line. Between Harvey and Pony gulch a rolling and slightly hilly topography, broken by numerous sloughs, plainly indicates that if any coal exists in Wells county west of Harvey it has been deeply buried in from forty to 100 feet of drift. An examination of the area in which the Pony Gulch mine is situated leads to the conviction that, while the seam outcrops further west in the direction of Dogden Butte, remnants of the seam may yet remain in Wells county. These remnants would probably be struck in wells between Harvey and Pony gulch, should any of them penetrate the thick surface layer of sand and gravel which overlies them. Few of the wells, however, are deeper than twenty-five feet, as good water is found on almost every farm at about that depth.

Pony Gulch mine lies about three miles north of the junction of two loops of the moraine. Hills of considerable size rise above the gulch on the south, while to the north are the low sand and gravel ridges above mentioned. The position of the hills gives the gulch an east-west direction, in which it extends for several miles as a low hollow bordered immediately on the south by a bench-like rise of land between thirty and forty feet in height. Bordering this bench in the hollow at the north lies a lake a quarter of a mile wide and a mile long with shores of clean sand. The drainage from the east seems to be toward this lake. The lignite outcrops in the lakeward slope of the bench. A closer inspection of the mine shows that the fifteen or twenty feet of clay, gravel and sand that overlie the lignite on the bench have been stripped away from more than an acre of ground, thus allowing access to the seam from the top. The lignite lies exposed to view in many places, but the following section probably furnishes the best idea of its position:

		FEET	INCHES
6.	Soil	2	..
5.	Gravel and sand	2	..
4.	Boulder clay	8	..
3.	Clay shading into sand	5	..
2.	Lignite	3	6
1.	Clay	Unknown depth	

The pit is easily drained into the lake at the north, and the only equipment necessary for working the mine is a plow and a scraper. Wagons are backed down into the pit and filled by the purchasers themselves from the pile of lignite broken out by the miners. This opening is said to have been worked for lignite for many years. A low estimate would place the coal removed from the mine at several thousand tons.

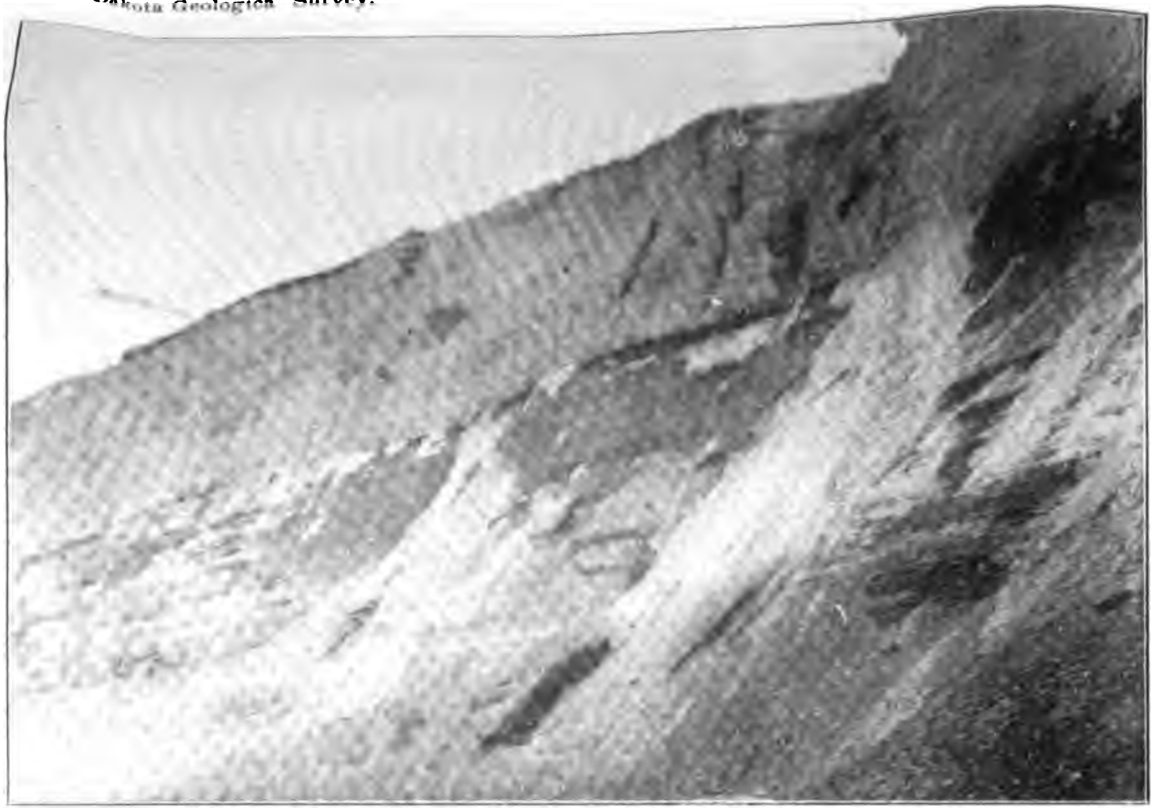
Other outcrops of lignite are reported from the gulch farther west, but of much smaller seams, sixteen inches being the largest.

The Dogden Butte Lignite Area.—This series of outcrops lies in the edge of the hills thirty-two miles west-northwest of the Pony Gulch mine. The outcrops of the Dogden Butte mines have been exposed by the post-glacial erosion of small coulee making streams flowing from the hills above the butte, while the lignite bench of Pony gulch was left by the ice practically without drift covering. Both series of outcrops face sloughs on the northeast, and in both the lignite seam extends back under the hills. They belong to the same horizon and have an elevation of about 1,600 feet. If these seams are assumed to be continuous, lying practically horizontal as they do, the trend of the seam to the west would bring it to a point 110 feet below the Missouri river at Coal Harbor. Again, following the seam to the northwest, it would fall in the horizon of the Hanchett, Turtle Gulch and Burlington mines. These outcrops furnish an illustration of the thickening of the lignite. The Pony Gulch seam averages three and a half feet; the outcrop one mile to the northwest reachs a maximum of eighteen inches. The Rose Hill vein has a thickness of eight feet, and the openings five miles to the northwest reach a thickness of but four feet. In the same horizon fourteen miles northwest of the Dogden Butte the seam reaches the great thickness of sixteen feet. Between these points the seam probably thins out to but a trace in some places. On the other hand, there are undoubtedly many places where the drifts and slips of native clay conceal a thickness of lignite which would well repay prospecting in a more thorough manner.

Dogden Butte, which furnishes a name for this small mining center, is a large hill of Laramie clay, surmounted by a great mass of glacial material. The entire butte stands out strongly in relief from the other hills in the background, rising some 300 feet above the flat, benchlike area bordering its base. Streams have deeply grooved its sides, forming coulees that direct the waters of the melting snows of spring in a dozen different directions towards the sloughs on the north and east. These coulees support a dense growth of cottonwoods, wild cherry, plum trees, and a large number of burr oaks, the oaks having a diameter often of fifteen inches. The unusual growth of timber in the larger coulees can be accounted for by the fact that they lie open to the northeast, a condition that protects the vegetation from the direct rays of the sun in summer and from the northwest wind of winter.

The streams that have formed the deep V-shaped channels at the base of the butte, not only carried away the drift covering, but also cut down into the Laramie clays in such a manner as to expose the lignite in many places. It is these wide open outcrops, and the ease with which the coal can be removed that have invited miners to this area, though it is sixteen miles from the nearest town. The mines extend over a distance of five miles, beginning with the Rose Hill mine at the south and ending with the Jones or Bentley mine at the north side of the butte.

The Rose Hill Mine.—The lignite of the Rose Hill mine outcrops on each side of a small coulee that heads back into the hill facing Dogden Butte on the south. A small stream of fairly good water issues from the coal. The seam lies thirty feet below the edge of the hill and twelve feet above the creek bottom, and has a thickness of five feet, appearing to thicken under the hill. The lignite is crushed and greatly distorted at the outcrop in the coulee, a condition due to slipping along the coulee slope. The seam is overlain with boulder clay, and a very sharp line of demarcation separates the lignite and the clay. The contour of the drift slopes bordering this coal outcrop on the north suggested the theory that the natural clay covering



A Twenty-Foot Lignite Seam Outcropping in Township 133, Range 104, Section 20.

the lignite was largely carried away by erosion previous to the advance of the ice, which in turn pushed off the remaining Laramie clay, substituting glacial till in its place. Possibly some of the coal was cut away from the surface of the seam at the same time. A shaft sunk a few rods further up the hill penetrates forty feet of drift and then discovers the seam of lignite which appears in the coulee, it having at this point a thickness of eight feet.

Mr Witz, the manager of the mine, will run his threshing engine to operate the mine during the winter and spring, using the shaft rather than the outcrops in the coulee, where the coal is more or less weathered. The following is an analysis of the dried lignites from this opening:

	PER CENT
Volatile matter	38.81
Fixed carbon	53.11
Ash	8.01

The other mines of this area are situated on the north side of Dogden Butte. Mr. F. B. Mosteller has filed a coal claim in Township 150, Range 79, Section 2. The seam measures four feet at this opening. At the opening owned by Mr. Parks, two miles northwest of the Mosteller mine, the seam also has a thickness of four feet.

The James and Bently Mine.—When the James mine was visited, its operator, Mr. Bently, was actively engaged in stripping the overlying fifteen feet of boulder clay from a large area of the lignite. This mine shows the following section:

	FEET	INCHES
5. Boulder clay	15	..
4. Lignite	2	..
3. Clay seam	..	4
2. Lignite	2	..
1. Clay	Unknown depth	

This mine is located just over the line of McHenry county, in Township 151, Range 79, Section 32. The seam outcrops for several rods along the coulee, and though it is but two or three feet above the creek level, it is well drained at the present time, as only a small quantity of water issues from the coal. The mine has been worked for four years and about 2,000 tons of lignite removed. Not the least of the conveniences which the enterprising manager, Mr. Bently, has arranged is that of selecting a trail that follows low ground almost on a direct line to Balfour, thus shortening the haul and furnishing a level road for customers. The analysis of the dried lignite from this mine is as follows:

	PER CENT
Volatile matter	37.72
Fixed carbon	53.77
Ash	8.51
	100.00

One other outcrop of coal was reported from this section, lying eight miles to the east, near water level in a coulee that drains to the sloughs north of the butte. Such an outcrop is not improbable, and is even to be expected from the level of the area intervening between the Dogden Butte mines and Balfour. This area includes a stretch of hilly ground, which, though drift covered, probably contains the lignite bearing Laramie series, lying at an elevation considerably above that assigned for the mines at Dogden Butte. The record of several wells of moderate depth in this area shows no lignite, but these wells all stop short at the water bearing gravel, thus failing to penetrate the deeper clays that might contain the lignite.

LIGNITE DEPOSITS OF MERCER COUNTY

Field work in Mercer county this summer was necessarily restricted to a small area, but statements obtained from reliable sources add materially to the data personally collected. The county will be studied carefully next summer, when it is proposed to follow the Knife river through the county from southwest to northeast, and to examine carefully the bluffs of the Missouri river which form its northern and part of its eastern boundary.

Lignite is distributed abundantly through Mercer county, and one of the first attempts to develop it on a large scale was made at Mannhaven, on the Missouri river. A number of years ago the Plenty mine, in Township 145, Range 84, Sections 5 and 9, near Mannhaven, was opened by eastern enterprise, and preparations were made to install an elaborate equipment. Flatboats were made to carry the lignite to points in South Dakota, and even farther down the river, but their construction being faulty they sank on their first trip, and the enterprise was abandoned. The coal seam at this mine is reported as thirteen feet thick with six inches of clay in the center. It is situated sixty feet above the waters of the Missouri. The Mannhaven Mercantile Company owns a mine near Mannhaven, in Township 146, Range 84, Section 7. The seam here mined, which is visible along the river for a mile and a half, is five feet above summer water level at its southern end, while it touches the water farther north. Its thickness is seven feet and the quality of the coal is reported as good. The mine is directly on the river and is worked during each winter, the amount of lignite taken out annually amounting to about 1,000 tons. Above the lignite lies a sandy clay.

In Township 145, Range 87, Section 31, lignite in workable seams is said to outcrop frequently, good springs occurring with it in great abundance. In Township 145 Range 86, Section 32, eight feet of lignite outcrop on a coulee. A coal bank is opened up here, the lignite being obtained by removing from eight to nine feet of clay. From Township 145, Range 85, Section 33, three feet of lignite of a rather inferior quality are reported. Mr. W. H. Mann, the founder of Mannhaven, is authority for the occurrence of a twelve-foot seam in Township 144, Range 87, Section 29, near the banks of the Knife river, and for another of the same size which outcrops in Township 144, Range 85, one mile south of the town of Deapolis.

LIGNITE DEPOSITS OF OLIVER COUNTY

Opportunities for natural exposures of the abundant lignite seams of this county are given by the Missouri river on the eastern boundary, and by Square Butte creek, a tributary of the Missouri, and branches of the Knife river. Most of the information at present available in regard to this county was furnished by Mr. W. H. Mann, of New Salem, whose standing in the community and long acquaintance with the county make his statements of great value. The following seams are reported by him:

LOCATION	AMOUNT OF LIGNITE	QUALITY
Township 141, Range 83, Section 28.	Abundant	
Township 142, Range 86, Section 9.	6 feet	Good
Township 143, Range 87, Section 3.	6 feet	Good
Township 142, Range 85, Section 9.	7 feet	

The county will be included in the field work of the State Geological Survey next summer, and work in this area promises to be very fruitful.

PRELIMINARY REPORT ON WARD COUNTY AND ADJACENT TERRITORY WITH SPECIAL REFERENCE TO THE LIGNITE

BY L. H. WOOD

POSITION OF WARD COUNTY WITH RESPECT TO THE LIGNITE AREA OF THE STATE

Ward county lies almost entirely within the lignite area of western North Dakota. Its eastern boundary line is a part of the line generally designated as the eastern limit of the lignite, while a survey of its other bounding lines would take one almost continuously across lignite seams outcropping very near the surface. Exceptions to this last statement are found in those places where the coteau crosses the borders of the county. Outcrops are not known between the Makee Brothers' mine, ten miles west of Portal, and the northeast corner of the county, though lignite may exist beneath the surface. A glance at the accompanying map of the county will show that extensive outcrops of lignite occur in the western and southeastern parts along the Des Lacs valley and in the northwestern corner.

The lignite field of North Dakota occupies the western half of the state and is divided by the Missouri river into two nearly equal parts, and of the northern, Ward county forms about half. The lignite area of Canada is continuous with that of North Dakota, the Roche Peree mines being but six miles north of the Makee Brother's mine, located but a few rods from the international boundary. Several outcrops occur between these two mines, showing that the seams are in the same horizon. Other areas closely associated with Ward county in respect to topography and deposits of lignite will be briefly referred to in this report.

AREA OF WARD COUNTY

This is one of the largest counties of North Dakota. Were it situated next to Connecticut or New Jersey, it would be plain that it outranks the former and compares favorably with the latter in area. Exclusive of the Indian reservation, the county contains about 5,500 square miles, or a little less than one-twelfth of the area of the state.

SOME INTERESTING GEOLOGICAL FEATURES OF THE COUNTY

Maps of the county suggest but few of its interesting geological features. There are, first of all, over 240 miles of river valley from a half mile to two miles in width, with hundreds of coulees of all sizes tributary to them. A part of the morainic system of the state, associated with the Coteau of the Missouri, from twelve to twenty miles wide, stretches across the county from northwest to southeast. As the county has very little timber land, the various types of erosion lie broadly open to view, furnishing a ready illustration of many important physiographic principles.

AGRICULTURAL POSSIBILITIES OF THE COUNTY

From a topographic point of view, something over one-half of the county is adapted to farming, while the rest is excellent ranch land, where thousands of cattle and horses not only thrive in summer, but also secure a good living during the entire winter. As to farming facilities, one need but observe the large number of grain elevators along the Soo road to become aware that the production of grain is not to be compared with the size of the houses of the recent settlers. At the present time almost every quarter section of land east of the coteau is held for farming purposes.

HIGHWAYS IN WARD COUNTY

With respect to railroads the county is very favorably situated. The Great Northern, with stations, on the average, every six miles, carries much of the stock to market. The Soo road runs 120 miles in the county, furnishing an outlet for quantities of grain and lignite. The present rapid development will soon make it profitable for an extension of the railroad system of the county. Wagon roads are numerous and extend to every part of the county where settlements make them necessary. The generally level surface of the prairie renders the construction of roads a very simple matter. When the ruts in the old trails become too deep, a new trail parallel with the old replaces it. Well traveled roads follow the river valleys and the railroads, and trails joining these lead to all parts of the county, except the remote and unsettled corners. Fair trails cross the hills at several points, while places in the southwestern corner of the county are situated on the very excellent government road.

ELEVATION OF THE COUNTY

The lowest point in the county is on the Mouse river in the southeastern corner below Sawyer, where the elevation above sea level is about 1,540 feet. Other elevations along the eastern part of the county are as follows:

Minot	1,557	feet
Burlington	1,590	"
Foxholm	1,675	"
Carpio	1,696	"
Donnybrook	1,760	"
Kenmare	1,799	"
Bowbells	1,958	"
Flaxton	1,956	"
Portal	1,954	"

The highest point in the northeastern part of the county is not absolutely known, but lies somewhere between Portal and Des Lacs lake, and is not far from 2,000 feet. The elevation of the Mouse river, at the point where it crosses the international boundary flowing south, is 1,650 feet. Adding 200 feet, the height of the Mouse river banks, to this 1,650 feet, gives 1,850 feet or about the level of the country east of the Mouse river. There may be a slight rise for five or six miles to the east, but beyond this point the drainage changes, and the creeks flow toward the old Lake Souris basin, which includes most of the area drained by the east arm of the Mouse. Between the Soo line and "the hills" in the northwestern part of the county, there is a fall in elevation toward the slough running parallel with "the hills;" but in general there is a gradual rise from the eastern boundary of the county to the center of the hill belt. The following are the elevations of places on the Great Northern road:

Surrey	1,635	feet
Minot	1,557	"
Des Lacs	1,902	"
Berthold	2,087	"
Tagus	2,187	"
Delta	2,263	"
Palermo	2,200	"
Stanley	2,253	"
White Earth	2,092	"

It should be noticed that Minot is situated in the Mouse river valley 300 feet below the prairie level on the west. Delta is the highest point in the hills west of Minot on the railroad, and about 700 feet above the Mouse river at Minot. But this elevation at Delta is the track elevation, and not the elevation of the highest point in the hills, which must be at least 200 feet higher. The height of Big Butte southwest of Flaxton cannot be far from 2,400 feet. The elevation of the Coteau du Missouri west of the hills is about 2,200 feet, or 460 feet above the level of the Missouri at the mouth of Little Knife river. The elevation of the county, then, is in general greatest at the western side with a gradual fall toward the east. A diagonal from the northwestern corner to the southeastern divides the county into two parts, the table land or Coteau du Missouri on the west, and the plain of the Souris river in the east. The eastern slope in the county is a part of the general slope from the Coteau du Missouri toward the eastern boundary of the state at the Red river.

RELIEF OF THE COUNTY

The absolute range in relief of the county, including the deep valley of the Mouse river, is about 900 feet. A line drawn from Surrey, on the Great Northern, in the eastern part of the county, to the prairie level at Stanley, situated on the Coteau du Missouri, rises from 1,635 to 2,253 feet, or 618 feet. In the first twenty-four miles, between Surrey and Des Lacs, the rise is 267 feet, or about eleven feet per mile. From Des Lacs to Delta, a distance of about twenty-four miles, the rise is 361 feet, or fifteen feet per mile. Along this line the plateau is not so sharply defined as from positions either twenty miles north or south of the Great Northern railroad, where the ascent to the hills is more abrupt.

The valleys of the Mouse and Des Lacs river system are the only exceptions to the generally level surface of the eastern half of the county. The western half is also broken by several stream valleys even more striking in appearance than the ones above mentioned, but less strongly contrasted with the more rugged surface of the plateau. A broad general division of the county into two parts can be made on the basis of surface regularity, a diagonal from the northwestern to the southeastern corner being the dividing line, and the eastern edge of the hills the most conspicuous landmark.

The portion of the county bordering on the Missouri and extending east to the center of the county has an elevation of 2,000 to 2,200 feet, distinctly set off from the eastern half of the county by a conspicuous range of hills. The highland, plateau-like area has received the name "Coteau du Missouri," and the hills rising from fifty to 200 feet above the coteau form its eastern margin. The belt of hills is a divide between the waters flowing to the Atlantic through the Missouri, and those that reach the Arctic ocean through the Red River of the North. The coteau has an extremely rough surface, in strong contrast with the plains lying east of it. While one may easily lose himself in the wilderness of hills, the plain lies so open that on clear days the grain elevators of Bowbells, Flaxton and Portal are distinctly visible twenty miles away.

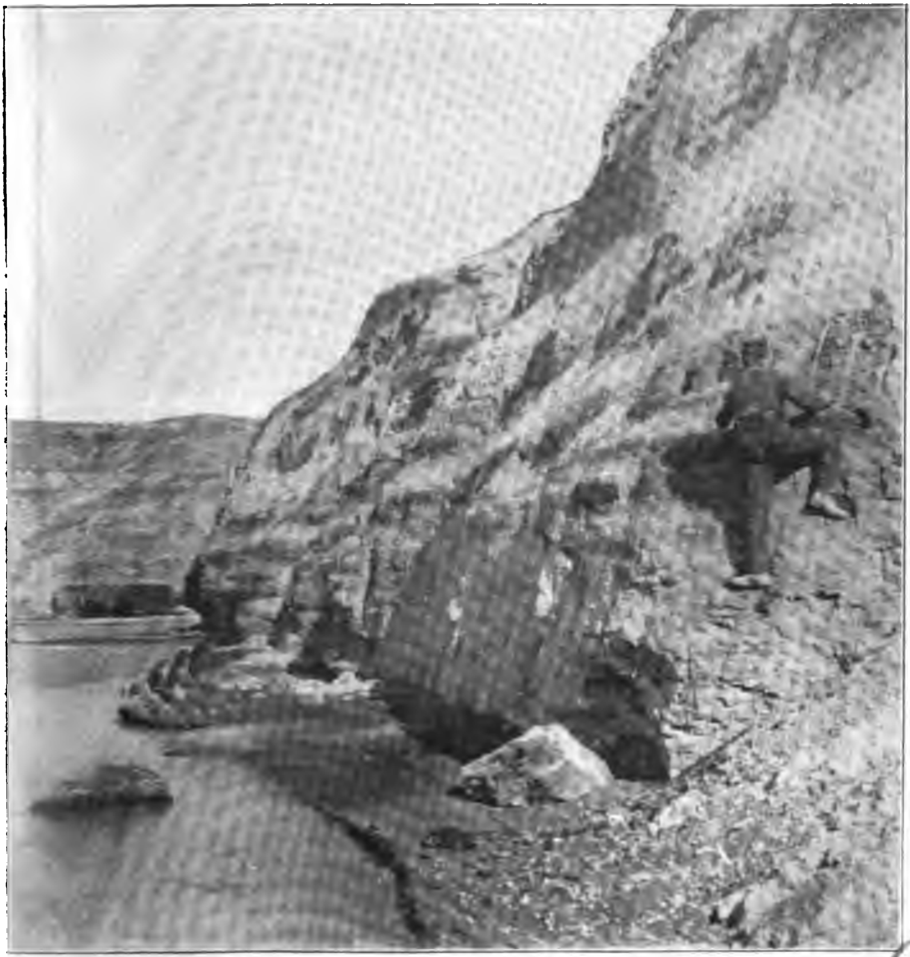
TOPOGRAPHIC DIVISIONS OF THE COUNTY

THE MOUSE RIVER BELT

The approach to the county on the east rises from the slope of old Lake Souris to the divide which, trending southeast, approaches within a very short distance of the eastern border of the Mouse valley throughout its full length in the county. In fact, the divide is so near that there are practically no eastern tributaries of the river. This belt is bounded on the west by the lower part of the Mouse, and by the Des Lacs river and lake. There are few coulees within the belt, and no conspicuous depressions aside from the broad, deep channel of the Mouse river and Des Lacs lake, which is really an old river valley. Small draws enter these valleys, making the approach to the river for a distance of from one to three miles on either side of the valley, very rought. Outside of the valleys the surface topography is that of a ground moraine, whose general level is that of a rolling prairie interspersed with sloughs. The northern part of this belt, though little settled, is said to contain some very good farming land.

THE COULEE BELT

The coulee belt borders the Mouse and Des Lacs rivers on the west, and contains fifty-one coulees between the southeast corner of the county and Kenmare its northward limit, a distance of seventy miles. In the portion of the belt between Galva and Foxholm they are very numerous, quite uniform in size, length and rate of growth headward toward the hills. In contrast with this portion of the belt, that below Minot contains fewer coulees, and these are larger, longer and more developed, in most cases



A Fourteen-Foot Lignite Seam Near 7 7 7 Ranch, on the Little Missouri. It Extends from the Water to the Top of the Hammer Above the Climber.

UNIV. OF MICH.

having narrow flood plains. One of the coulees in this belt along which lignite is mined is shown in plate XVIII.

The streams of the coulees are for the most part dry in summer, or reduced to a series of muddy pools. The head waters of the southern half of the belt are already working on the margin of the hills, while the shorter ones at the north are rapidly approaching them. As would be expected, the topography of the coulee belt is much affected by the numerous small valleys, most of which are in early youth, having the appearance of deep trenches. The lateral tributaries are few in number, so that the intervening prairie has hardly been touched by erosion. This entire belt, having an area of from 700 to 800 square miles, slopes gradually from the margin of the river valley on the east to the base of the hills at the west, rising between 200 and 300 feet in ten miles.

The portion of the county northwest of Kenmare may be divided into two parts, the northern continuous with the Mouse river belt from the east, though decidedly more rolling. Potholes, sloughs and hills of gravel and sand rise in places almost to the dimensions of drumlins. The southern part of the area is a depression about thirty miles in length, running from five miles west of Bowbells to the western boundary of the county, at Township 163. This depression contains several shallow lakes, and receives the drainage both from the hills on the south and from the rolling prairie on the north. Small creeks, gathering their waters from the western end of this depresison, flow north, unite just above the boundary line and finally enter the Souris or the Mouse river, to be carried by it around through the eastern part of the county. Coulees from the hills tributary to this depression are almost as large as many of those entering the Mouse river valley. Running for twenty miles or more in this depression is a bench containing minor outcrops of lignite, laid bare by the creeks that cut through the bench as they flow from the hills to the sloughs. This topographic feature is well brought out on the accompanying map.

THE HILL BELT

Ward county contains a section of the Altamont moraine, or first moraine of the Wisconsin drift, ninety-five miles long, stretching from the northwestern part of the county, in Township 161, to the southeastern corner. The trend north of Township line 161 is west-northwest into Williams county. It has been traced more or less accurately from the Saskatchewan river, in the central part of Assiniboia, southward through North Dakota, across South Dakota, and as far south as Des Moines, Iowa. In width the hill belt varies from fifteen to twenty-five miles, the limits as yet having never been sharply defined. Taking fifteen miles as the average width of the belt, the area of the hill land included within the county is about 1,500 miles. The roughness of the hills is almost equal to that of the bad lands, but the nature of the relief is entirely different. Bad land topography is due to erosion, this to deposition. The bad lands are characterized by few undrained areas. In this belt the slope of one hill so blends with that of others about it that sloughs, pot-holes and lakes are inevitable. As one traverses the area he may pass for miles through a section where all the hills have about the same height, shape and regularity of arrangement, and then comes suddenly upon a broad amphitheater-like depression surrounded by a wall of hills, from which there seems to be no exit to the area beyond. Sloughs 100 feet below the average level are not uncommon, and small ones are so numerous that a dozen may be counted from a single hilltop in some parts of the belt. Many of the shallow sloughs are valuable grass lands, sought out by the ranchers, who come several miles to cut the rich marsh grass that grows along their margins.

The junction of the hills with the coulee belt on the east is rather abrupt, while on the west the approach is very gradual, almost inappreciable. The hills really form a margin to the plateau of the Missouri, and blend with the plateau along its eastern edge. This fact comes out very strikingly as one passes from some point on the west, such as Coal Harbor, toward the northeast. For, after riding eighteen miles among the hills which intercept his view on every side, the traveler comes sharply out upon the edge of the belt from which he can look down and away twenty miles to the east toward the Mouse river. The small farms of the coulee belt with their green flax fields present a striking contrast with the yellowish-brown grass on the hills, withal very refreshing to one who has been traveling for several days along the untilled stretches of the Missouri country.

THE PLATEAU AREA

West of the hills the general elevation of the country is higher by 300 feet than the coulee belt on the east. Its relief is bolder and more impressive than that of any other part of the county. The effect is due to the size of the valleys that extend from north to south through the area. Though the streams are mere creeks, only a few feet wide at most during the summer season, the valleys through which they flow are over a mile in width on the average, and extremely crooked. Many tributary coulees enter the main valley, so that the area of rough and broken country along these streams is several miles in width. If the valleys of the White Earth, Little Knife and Shell creek are compared with the valley of the Mouse, the irregularity in the course of the former is noteworthy, the zigzag valley of the White Earth differing greatly from the straight canal-like valley of the Mouse. This statement does not apply to the present stream channels, but to the broad valley in which the streams flow. The streams also differ greatly in the number of tributaries. The difference is due largely to the fact that the Mouse valley has been greatly modified by the deposition of drift, while the White Earth was almost free from these effects.

If the area of the other three belts is subtracted from the surface of the country, there remains for this triangular section of the plateau belt about 1,800 square miles, exclusive of the Indian reservation. The larger part of this area is yet in its natural condition. The plateau area presents some interesting topographic features. The series of large lakes situated along the western side of the hill belt has a history not yet completely read. The lakes at the head of the Shell creek are a part of the headwaters of the stream, which have been obstructed and cut off from the valley by the accumulation of drift. The lakes near the head of the Little Knife and White Earth rivers probably have a similar origin. The sloughs at the head of the White Earth are undoubtedly of glacial origin. The abrupt termination of the Little Knife river valley, just south of Stanley, may be related in some way to the formation of the sloughs and lakes lying to the north and east of that place.

DRAINAGE OF WARD COUNTY

The most significant fact about the drainage of the county is its incompleteness. Sloughs occur in all parts of the county and are numbered by the thousands. For the most part these individually coyer a very small area, and are so shallow that many of them may be used for hay land late in the season. Some of the basins in the hills, however, attain an area of several square miles and have an abundance of water. The Des Lacs and Mouse river system furnishes but a very imperfect drainage to the area northeast of the hills. Though the valleys proper are well developed and mature in aspect, their tributaries were largely obliterated during the glacial period; while the more recently developed coulees are still in extreme youth and reach but a small part of the area which they will eventually drain. In the eastern part of the county small streams have begun to work back from old Lake Souris in a northwesterly direction.

The hill belt has been practically untouched by erosion agents, so that very few of its many ponds have yet found an outlet. Many small creeks are working headward along the approaches to the hills, toward the sloughs that will ultimately fall a prey to their activity. The plateau belt west of the hills is scarcely further along in its drainage history than the eastern half of the county, the county immediately bordering the valleys of the streams is cut up by lateral tributaries, but only a few miles from the best developed creek, the White Earth, sloughs abound.

Traces of a more mature system of drainage of the Laramie epoch are seen in many places, but more conspicuous are the changes wrought by the glacial ice upon all previous waterways. Whatever the preglacial system of drainage may have been, at present the country lies within a rejuvenated area, the streams of which are just beginning their work upon this cycle of erosion.

STRATIGRAPHY

In Ward county there is but one series of strata outcropping, and that is the Laramie clays. The eastern boundary of the county lies not for from the eastern edge of the Laramie. Considering all earlier rocks, then, as lying entirely at or below the level of the lowest point in the county, the mass of Laramie included within the limits of the county forms a section having a thickness of from 100 to 300 feet along the eastern edge and thickening to a depth of 900 feet at the western boundary. A cross-section of this area taken at either the northern or southern end would show a series of clays, sandy shales and lignite seams, with sandstone layers at irregular horizons between the top and bottom, a section similar to that of Sentinel Butte. The only difference between a section from east to west in the vicinity of Sawyer and at Portal consists in the relative thickness of the strata at the east and west sides. The section at the north would be nearly uniform in thickness from east to west.

Other outcrops of the Laramie to the east of the county are found in the Turtle mountains in the north central part of the state. The series of strata lying between these outcrops in the east and and those in the west were largely eroded away in preglacial times. Ward county lies within the eastern limit of the western area, and is a part of the body of clays and shales that extend far west into the Rocky mountain belt in Montana and Wyoming. Throughout the extent of these strata, or at least in Montana and Wyoming, lignite occurs in large quantities. In quality it becomes more bituminous toward the west, in Wyoming, where apparently disturbances of the strata have led to greater carbonization.

All observations up to the present indicate that the strata lie in a horizontal position. No real fault has been discovered, though there is much slipping along the valleys, which appears like faulting, due to the break in the continuity produced in some of the lignite mines. The thickening of the Laramie in the western part of the county is not due to greater deposition, but rather to the fact that the strata in the eastern half of the county have been carried away by the general erosion which affects the eastern section of the state. It is not probable that the greatest thickness of the Laramie occurs within the county, for, at Sentinel Butte, the lignite bearing strata rise beween 600 and 700 feet higher; while a similar series in the vicinity of the Bow and Belly rivers in Alberta has a thickness of 5,750 feet composed wholly of fresh water deposits except near their base.*

It is doubtful whether the next underlying series of strata, the Fox Hills sandstone, outcrops anywhere within the county, though low lying beds of sandstone, along the Mouse river might be so regarded. The workable seams of lignite lie in the Laramie and probably entirely above the 1,500 foot level, or about the level of the Mouse river at Velva.

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* Upham, Glacial Lake Agassiz, p. 85.

Most of the prevailing Laramie formations consist of an unconsolidated, more or less sandy clay and sand. Little true shale outcrops in the county. Locally the sand has hardened to a dense, gray, fine-grained sandstone. Numerous seams of ferruginous clay are frequently found hardened to stone that breaks with a flinty fracture. Such a seam of ironstone a foot thick occurs on the Des Lacs river, four miles above Burlington. The sand is universally fine grained, and in many sections shows a tendency to weather in nearly vertical faces. The following section was taken from the face of a bluff in a coulee four miles above Burlington on the Des Lacs river:

TP. 156, R. 84, SEC. 29		FEET	INCHES
5.	Till	8-20	..
4.	Ferruginous clay and sandstone	2	..
3.	Steel gray sandstone	30	..
2.	Yellowish brown sandstone	5+	..
1.	Water level in the creek.		

Number 3 in this section shows well developed cross bedding. Number 2 is a thick bedded sandstone that contains many black, scale-like particles, probably of mica.

A section similar to the above appeared on the opposite side of the Des Lacs river.

Another outcrop more characteristic of the Laramie was seen one mile above Donnybrook, and repeated at many points between this place and Kenmare, further up on the river.

Section one mile north of Donnybrook:

		FEET	INCHES
22.	Yellowish clay	1	6
21.	Lignite	..	6
20.	Clay	1	..
19.	Lignite	..	6
18.	Sandy clay, light gray	10	..
17.	Hardened sand becoming clayey	8	..
16.	Carbonaceous matter	..	6
15.	Clay containing iron and gypsum	3	..
14.	Carbonaceous matter	..	4
13.	Clay containing iron and gypsum	6	..
12.	Carbonaceous matter	..	3
11.	Clay	1	..
10.	Carbonaceous matter	..	4
9.	Yellow clay	7	..
8.	Black clay	..	6
7.	Very sandy clay	8	..
6.	Chert-like clay ironstone	6-8	..

	FEET	INCHES
5. Clay	2-3	..
4. Lignite	..	3
3. Sandy clay with many thin seams of yellow ochre-like substances	16	..
2. Lignite, fossil tree stumps in situ	1	..
1. Clay containing much sand, with many small marble-like concretions	30	..

The dip of the strata in the above section was slightly to the southwest, due probably to a slipping of the whole mass. The clays and sand are, in general, practically unconsolidated, so that wherever open faces of bluffs are found the material is easily subject to erosion by wind and water. Along the river valleys land slips are common, in some instances large masses of material being involved. Along the upper Des Lacs valley, where till is for the most part absent, slips are so numerous as to modify the naturally steep slope very materially. In many cases the body of the clay carried to the base of the bluffs obscures entirely the lignite seams. On account of this slipping miners count on a rise of the seam from the point where entries are first made in the slope. Such a slip occurs in the Electric mine at Kenmare, as shown in figure 7.

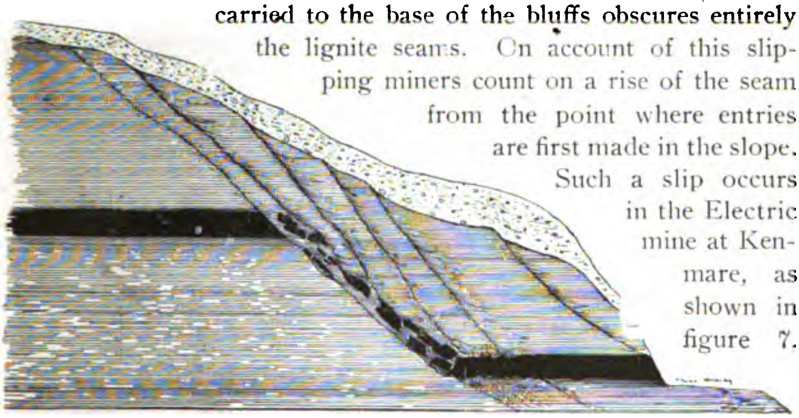


Fig. 7. Diagram showing a slip in lignite and clay at the Electric mine, Kenmare.

Some of the bluffs along the Missouri in the southwestern part of the county, where undercutting is rapid, rise from the river at an angle as great as sixty degrees. The following sections, which might be duplicated many times in the high bluffs along the Missouri, will give some idea of the series of clays of which the Laramie is built up:

	FEET	INCHES
18. Clay (light gray)	20-30	..
17. Clay (bright yellow) persistent for miles along the river	15	..
16. Clay (light yellow)	10	..

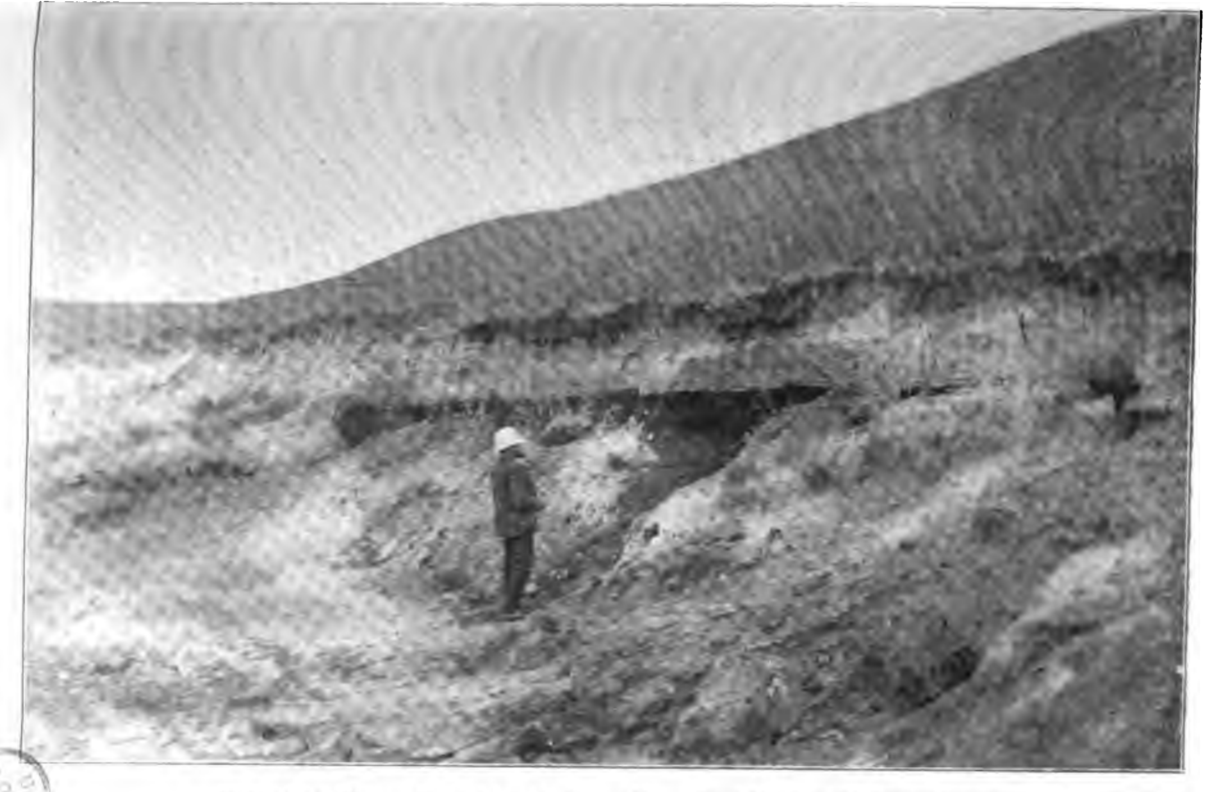
		FEET	INCHES
15.	Clay (light drab) fossil wood horizon	20	..
14.	Carbonaceous shales containing carbonized plants	1	..
13.	Clay (dark yellow)	30	..
12.	Clay (yellow), burned to a red slate-like fissile shale	20	..
11.	Lignite	1	..
10.	Clay (light gray)	20	..
9.	Lignite	2	..
8.	Clay (light yellow), containing limonite seams	30	..
7.	Stiff sandy clay (light blue)	20	..
6.	Lignite	1	..
5.	Sandy clay (blue)	6	..
4.	Lignite.	1	..
3.	Clay (light gray) with sand locally hardened	20	..
2.	Lignite	3	..
1.	Clay	30	..

This section does not exaggerate the contrast that stands out strongly everywhere in the color and succession of the clays that compose the Laramie. The color effect is heightened by the presence of a layer of red burned clays at the top of the butte in many places.

Sand may occur, as was observed in many places, at various horizons, locally hardened into layers, varying in thickness from a few inches to twenty feet. It may take the form of concretions, some of which are cylindrical, having the appearance of logs. This form is very striking, inasmuch as the so-called logs appear to be cut in sections of uniform length with ends as squarely broken at the joint planes as if they had been sawed. Other portions remain in an upright position, resembling stumps from which logs have been cut.

Another striking characteristic of the Laramie series is the number of lignite seams. As many as nine of these seams were counted in the face of a single bluff. At Hofflund, eight seams, with a thickness of from six inches to three feet, run continuously, without great variations, for two miles along an almost vertical bluff. Locally, these lignite seams thicken up to six, eight and eleven feet.

For further observations upon Laramie formations reference may be made to Dr Wilder's discussion covering the area of Laramie clays and lignites as a whole.



Part of an Eleven-Foot Lignite Seam Near Coal Harbor, McLean County.

NATURE OF THE PREGLACIAL SURFACE OF THE LARAMIE

Any discussion of the preglacial surface of the Laramie in the county must be largely hypothetical, since at the present time few facts bearing upon this question are at hand. It is an interesting one, however, not only on account of its relation to glacial problems, but also because of the position which the lignite occupies with respect to the drift.

Observations along the southwestern border of the moraine, in the river valleys and in the mines, lead to the belief that the surface of the country, now covered more or less completely by drift, was once much more broken than at present. Low hills are found east of the edge of the moraine, hills that are merely old buttes covered with glacial material. Just southeast of Kenmare, in a railroad cut on the lake front, old erosion surfaces appear under the drift. In some of the mines old channels are found filled with boulder clay. On the higher hills along the eastern margin of the moraine, some, at least, consist of a base of Laramie strata. The valleys of the Mouse and Des Lacs rivers are today almost without tributaries of dimensions corresponding with the main valleys. Commensurate tributary valleys must have existed in preglacial days, and their presence would have increased the roughness of the surface in the same way as those of the Little Knife and White Earth. It does not seem unlikely that the surface of the county was more or less broken in a maner approaching that of the bad lands. The banks of the streams were generally steep; sharp slopes prevailed everywhere, and the butte was the common type of hill. Here and there in the county, a remnant of an earlier base level might have been seen, such as the hill of Murdered Scout, just over the line in Canada, northwest of Lake Des Lacs, or like Dogden Butte, in McLean county. The general level, however, must have been lower toward the eastern part of the county to have maintained the slope between the Missouri and the Red river that is found at present.

When the amount of denudation and the general lowering of the surface due to glacial action is considered it is not safe to assert that more material was removed than was deposited. Much of the clay constituting the base of the till in the moraine doubtless was carried but a short distance. A part of the material brought to the area was deposited in old valleys, while the more prominent elevations on the surface were broken up and incorporated with the masses of clay, boulders and gravel and carried to points farther on. The great change in topography was due to leveling, the two factors of which were filling of depressions and cutting down prominent elevations. As a result of this process, in which of necessity much material was irregularly deposited, some points are higher and some lower than they were before the advance of the ice. The number of lignite outcrops in preglacial times must certainly have been greater than now, as the relatively few exposures that now exist in the glaciated area are due to the recent removal of drift.

DRIFT IN WARD COUNTY

There are but few townships in the county where the Laramie formations are not entirely hidden from view by drift. This is equivalent to saying that there are few parts of the country where the surface remains unmodified by the drift. The deformations and modifications may have come about through several processes, one or more of which were active over some part of the entire country. These processes consist of (1) erosion by the body of the ice carrying debris on its lower surface; (2) deposition of parts of the material carried by the ice; (3) deposition at the edge of the ice due to melting; (4) deposition of materials carried by the waters flowing from the melting ice; (5) erosion by the waters from the margin as well as from under the ice; (6) final deposition of rocks and debris held in the body of the ice, and (7) a combination of one or more of these processes. The nature of the change occurring in any particular area will depend upon the position of that area with respect to the margin of the ice as it stood in the most advanced position. Areas lying under the ice would be affected both by erosion and deposition, and also by pressure due to the weight of the incumbent ice. Areas along the extreme margin would be modified most by deposition of material. Areas beyond the range of marginal depositions by the ice would be affected by erosion of waters flowing from the melted ice and also by deposition of assorted materials, such as gravel, sand and clay. Areas between the terminal moraine and the retreating margin of the ice would be greatly affected by the streams flowing from the melting ice Material deposited by the ice, directly, would be unassorted, consisting largely of till or clay with pebbles and boulders in all parts of its mass. Materials deposited by the waters flowing from the ice would be variously assorted, and the resulting hills and banks stratified as a consequence. The sand, gravel and clay would be deposited in layers in a more or less definite series.

Area of the Ground Moraine.—The entire northeastern half of Ward county lay under the ice sheet during its advance to the position at which the hill belt was formed. While assuming this position, and during the more or less continuous advance necessary for the building up of such a terminal moraine as that represented by this belt, the ice filled up many old valleys in the county, scoured down elevations, and left a coating of till varying in thickness from nothing to 100 feet or more. The maximum depth of the till has not been determined, but in many instances wells have penetrated it for 100 feet. Wells having a depth of from thirty to fifty feet, with bottoms in gravel, are very common in the northern part of the county. The following illustrations show how the thickness of the drift varies in the county northeast of the hills:

A well ten miles west of Portal and one mile north of the Canadian boundary, twenty feet deep, strikes a lignite seam.

A well seven miles west of Portal penetrates forty feet of sand.

Seven miles east of Portal a well passes through forty feet of yellow and blue clay without reaching the bottom of the till.

In Township 162, Range 90, Section 1 or 2, northeast of Flaxton, gravel is reported at the bottom of a well 130 feet deep.

In Township 162, Range 90, Section 1, a well 100 feet deep passes through gravel and till to the bottom.

In Township 162, Range 91, Section 9, a well is reported on good authority to be 175 feet deep, and to pass through stony clay all the way to the bottom.

West of Carpio, several wells penetrate from forty to fifty feet of till.

The shaft in the New Era mine, ten miles west of Minot, penetrates forty feet of till, though the shaft entrance is between thirty and forty feet below the level of the surface.

At the Hanchett mine, in the southeastern corner of the county, about twenty-five feet of till lies above the lignite. At the Turtle Gulch mine, a few miles to the north, seventy feet of till covers the same seam.

Along the edge of the stream valleys the drift is usually thinner, due to erosion. For a more definite determination of the thickness of the drift data are not at hand. From the few facts mentioned it will be seen that the thickness varies considerably. South of this county, where the drift has been more carefully studied,* much greater thicknesses have been assigned. The average for Ward county is probably much less than 100 feet. A large part of this material is composed of clays, furnished from the areas adjacent to points where the whole mass was deposited. In the wells that penetrate this bed of till, the first fifteen or twenty feet of material consist of yellow clay and the remainder of blue clay. The difference in color has been explained by Upham † as due to the influence of air and water upon the iron contained in the deposit, changing it from protoxide combinations to hydrous sesquioxide. Other explanations perhaps more satisfactory will be considered in a later study of the drift deposits of the state.

The lower drift seems to be much tougher than the upper, due, possibly, to the greater pressure to which it has been subjected by the weight of the overlying ice.

The nature of the till varies somewhat, but in general it consists of clay, generally plastic, containing pebbles of all sizes from a grain of sand to boulders. The smaller pebbles predominate and are usually somewhat rounded, due to the rough handling they have received in their journey under the ice. If one were to mix the native clay with the pure gravel from a gravel terrace, in proportion of one part of gravel to from five to ten parts of clay, he would have a fair till. Locally the till is filled with stones of a larger size, and a well can scarcely be dug anywhere from which a dozen boulders from six inches to two feet in diameter are not brought up.

Terminal Moraine.—No extended observations have ever been made, so far as can be learned, upon the moraine belt of the county. It is generally known as an exceedingly rough area, consisting of knob-like hills interspersed with many sloughs and small lakes. The eastern boundary of the moraine is well marked, as it can be seen fifteen miles away, appearing not unlike a great river bluff, except that its upper edge had a more serrate outline. The western limit is much more difficult to assign, because it gradually shades off into the plateau beyond it. Some of the hills are veneered buttes without doubt, but the majority of them, as appears from the railroad cuts, consist of till from bottom to top. The till is not unlike that of the ground moraine, though the per cent of gravel and assorted material is greater in the hills. The varied topographic forms of the terminal moraine are due to deposition, only slightly modified by erosion. Post-glacial erosion mainly in the coulees along the eastern slopes, has drained but few of the multitudes of sloughs.

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* Upham, Glacial Lake Agassiz, p. 133.

† Glacial Lake Agassiz, p. 135.

Outwash Gravels.—As one approaches the western side of the moraine, gravel and stratified material become more numerous, and evidences of water action, both in the sorting and in the deposition of material, are abundant. Toward the head of the valley of Shell creek is a broad, gently sloping plain several miles long and a mile and a half wide, with a surface of unusual flatness. This plain is entirely faced with gravel several feet thick. This is probably an outwash plain and at present drains to the sloughs at the head of the creek. Following still farther down Shell creek, gravel terraces rising fifteen feet above the creek furnish an excellent roadbed for many miles along the valley.

White Earth creek shows a similar deposit of gravel at various points, while many terraces along the Missouri, and gravel banks with stratified material in the vicinity of Stanley and Palermo, point to the fact that large quantities of water flowed over these areas, depositing coarse material and carrying the finer farther on.

Whether the large terraces of gravel occurring along the Missouri are due to the outwash from this moraine or another of greater age lying partly south of it has not been positively determined. Evidences of an older drift sheet were seen at several places along the Missouri, and the terraces may be associated with it.

Drainage From the Edge of the Retreating Ice.—By referring to the map of the county it will be seen that in the northwestern part of the county there is a series of large sloughs. These extend in a direction parallel with the hills, and are partly drained by creeks to the Souris river at the north. With an ice sheet lying to the north of the sloughs, but having its edge south of the present Souris valley, drainage could hardly have had the direction which it now takes. Much of the water must have been carried off to the south. That considerable erosion accompanied the flow of the waters is shown by the depression of the slough below the level on either side. The surface of the bench bordering the sloughs here for a distance of twenty miles has scarcely any drift covering, so little, in fact, that coal outcrops at many points, as shown by the map. On the other hand, had deposition in quiet waters taken place in front of the ice, as might be expected, the bench area would be deeply covered. Some outlet for the sloughs toward the Des Lacs valley may exist, but it has not been traced to its terminus.

Drainage From the Area Covered by the Ice.—The valleys of the Mouse and Des Lacs furnished a ready outlet for the waters of the melting ice. So much gravel and sand occur in the Mouse river valley, facing the slopes on either side, that all natural outcrops of lignite are concealed. At Minot, and especially at Velva, large gravel deposits occur. Gravels older than Wisconsin were found at Minot, in the Mouse river valley.

If the valley is the work of outflowing water of the late Wisconsin drift sheet, it is difficult to account for the presence of this old gravel. The great uniformity in the course of the valley and the absence of tributaries of any considerable size point to considerable modification, if the valley was preglacial. The boulders are entirely foreign to the county and are scattered apparently without law or order through the till in large numbers. Along the valley of the Des Lacs river, between Burlington and Carpio, there are terraces whose surface is literally paved with these rounded and subangular blocks of granite, gneiss, syenite, diabase and limestone. Boulders also are abundant along the valley sides and in the coulees. At many of the gulches where coal outcrops, gray, black and pink boulders, red with the rust-covered lichens, cover the surface. Several were seen delicately poised on sandrock pedestals. A case of this kind occurs at Velva on the Des Lacs river, where a boulder weighing twenty-five tons rests upon a support of sandrock not more than a foot in diameter. Many of the high bluffs along the Missouri are thickly covered with boulders, small and large, while along the White Earth creek several places were seen where the valley had received a consignment of boulders, as though pushed over the valley wall from the sides.

Limestone boulders form only a small per cent of the whole number, but still they occur locally in numbers sufficient to be profitably burned for lime.

Terraces and Ancient Valleys.—On the Indian reservation south of the Little Knife river, and west of Shell creek, an interesting phenomenon was noticed. The escarpment of the Missouri, which one would expect to find following the river, instead follows a line running almost straight from the first sharp bend of the Little Knife to the Missouri five miles southeast of the mouth of Shell creek. Between the escarpment and the marked semicircular bend of the river, there is a valley running parallel with the escarpment, varying in width from one to two miles. This valley is separated from the river on the south by drift hills whose elevation increases toward the Missouri on the south and west. The fact that many of the hills are boulder covered and the abundance of sloughs plainly mark the area as within the glacial drift. One long, pond-like slough is especially noticeable, as it extends from a point near the center of the area straight toward the west for several miles, apparently opening out into the valley of the Missouri. That the water of this pond has been higher than at present is shown by the gravel terrace that closes its eastern end.

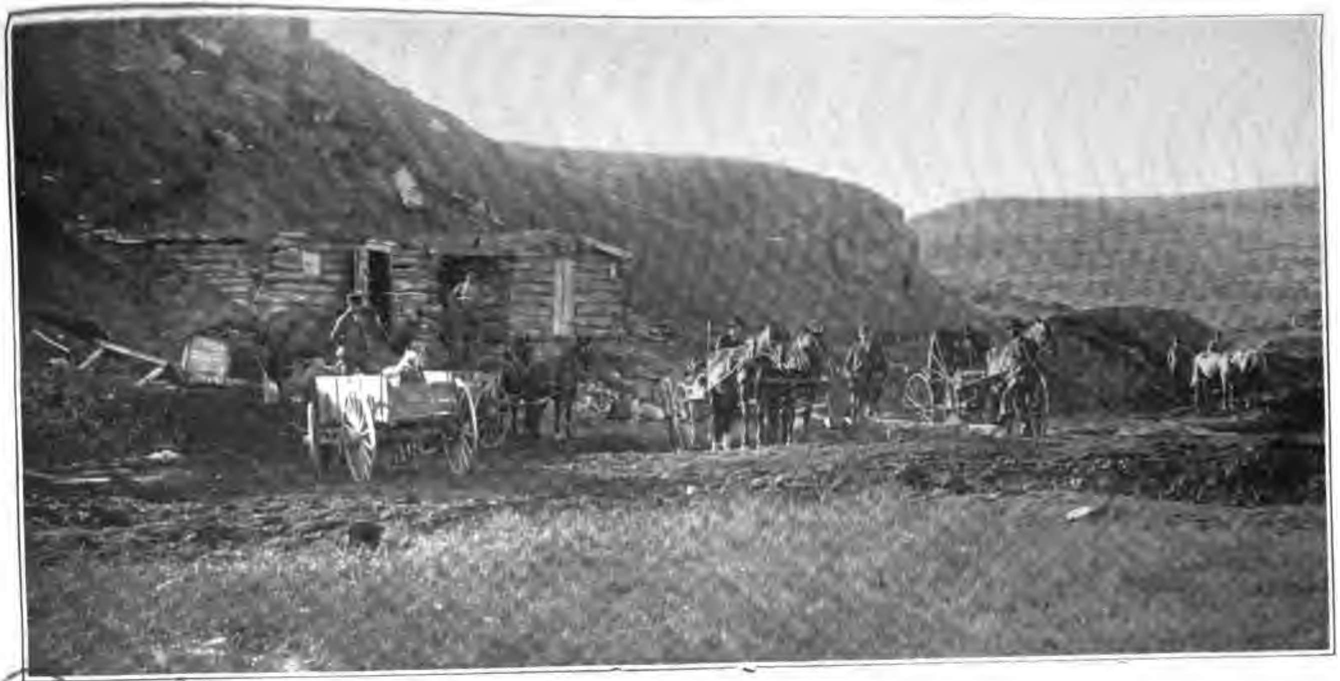
This series of drift hills bordering the Missouri extends from a point three miles west of the mouth of the Little Knife to the mouth of Shell creek, with the exception of the break at the Little Knife river. At the east end of the valley that borders the escarpment, there is a gravel terrace forty to fifty feet high and four miles long, trending to the northeast. This terrace is remarkably flat, and, except for the small gullies that cut into its edge here and there, the surface is as level as a railroad bed. It faces another broad flat at the east twenty or thirty feet lower, along the south edge of which the Missouri is cutting at present, still twenty feet lower down.

At the west end of the drift hills and continuous with them are other remnants of a terrace having about the same elevation as the one just described. This terrace extends from Nesson in Williams county more or less continuously to the mouth of the Little Knife river. It is especially well developed at Nesson, Grinnell and Chilcot, where it is unusually striking, due to its position with reference to the old escarpment. Flat topped and bench-like in appearance, it protrudes abruptly outward a mile or more from the bare clay faces of the buttes that rise 200 feet above it in the background, while its even edge bounds a rather sharp but still uniform slope from the first terrace below it on the river. In many places between this higher terrace and the steep slopes behind, streams have eroded narrow V-shaped valleys. These same streams have cut through the terrace in many places plainly showing that drift is the only material in its composition. Parts of the terrace, in a position to have been much washed and assorted by the action of the water, consist largely of gravel.

Associated with this old valley of the Missouri on the reservation is another, probably of similar origin, extending from Nesson to Hofflund. While the valley is not as long as the one uniting the "big bend" of the Missouri, it is fully as wide, and is interesting in its details, while, as a depression, it is more sharply set off from the slopes. A gravel terrace of magnificent proportions bounds the valley on the west and south, extending for five miles along the river terraces below it.

More remarkable than either of these old valleys is the depression running from the valley of the White Earth, eight miles above its mouth, to the Missouri at Hofflund. Coulees cut far back into the slopes of native lignite bearing clay on the north side of this depression, while drift covers the opposite slopes, which rise gradually from the bottom of the depression to the top of the bluff overlooking the Missouri valley at an elevation of 350 feet. The slopes on this side are clearly drift veneered only. Boulders are numerous all the way to the top of the bluff. Wells in the depression show the valley to be drift filled. At the east end terraces of gravel occur in the White Earth valley, and the west end is drained by Dry Forks creek. Whatever the history of the stream that eroded this depression, the depression itself is clearly tributary to the old valley of the Missouri at Hofflund.

Deep Wells in Ward County.—Any discussion of the subject of wells in the county makes a reference to the strata lying below the Laramie necessary. No deep wells have been bored within the county so far as has been learned, for which reason it is necessary to resort to data furnished by other parts of the state.



The Satterlund Mine in McLean County.

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The series of formations occurring just above and below the Laramie are shown by the following table:

GROUP	SYSTEM	SERIES	STAGE	SUB-STAGE	FORMATION
Cenozoic	Pleistocene	Recent			Alluvium
		Glacial	Wisconsin		Moraines Gravel Sand
			Kansan?		Drift
Mezozoic	Cretaceous	Upper	Laramie		Clay Sand Sandstone Lignite
			Montana	Fox Hills	Sandstone
				Pierre	Shales
			Colorado	Niobrara	Shales
				Benton	Shales
			Dakota		Sandstone

In the upper or glacial series of strata, consisting of till, gravel and sand, shallow wells are found at many places in the county at depths ranging from twelve to fifty feet. Wells of this class in which the water is good and the supply ample have as a reservoir a pocket of gravel in the till, or a surface deposit of similar gravel and sand.

If the water is not obtained in the drift materials, the prospect for getting a good flow of water from the underlying series of Laramie strata, especially the clays, is not good. In a number of instances, however, a fairly good supply of water has been obtained at some one of the lignite levels. In such cases the lignite seam is probably the water bearing member, lying as it does between two seams of impervious clay.

Some good flows of water have been obtained in the sand that occurs irregularly bedded in the Laramie. A well at Medora (figure 2) penetrates the shale, lignite and sand, members of the Laramie, for a depth of 941 feet. Water was obtained at two levels in this well, the first being at about 500 feet, the second at the bottom, the flow rising 100 feet above the surface. The water from this well is soft and somewhat sulphurous, and the flow thirty-three gallons per minute.*

The depths to which borings would need to go, in order to reach the Dakota sandstone which furnishes the large artesian wells of other parts of the state, is probably not far from 200 feet below the sea level. This estimate is based upon the record of the nearest artesian wells north, east and south of Ward county. At Deloraine, northwest of the Turtle mountains and forty miles from the nearest point in the county, an unsuccessful well reaches a depth of 1,894 feet without penetrating the Dakota sandstone, showing that the Dakota lies more than 156 feet below sea level. At Devils Lake the sandstone is struck exactly at sea level. At Jamestown the surface of the Dakota is found lying seventy-six feet below sea level, showing nearly a constant elevation along the north-south line passing through the last named places. As the dip of the stratum of sandstone in the part of the state lying immediately west of the line from Jamestown to Devils Lake is slightly toward the west, the portion underlying Ward county is estimated to be from 150 to 200 feet lower than its elevation at Devils Lake. According to these figures the depth to which boring would need to extend in Ward county to reach the great water bearing horizon, the Dakota sandstone, can be approximately obtained by adding 200 feet to the surface elevations which have already been given for the leading points in the county.

LIGNITE IN WARD COUNTY

General Considerations.—It becomes evident, after a very brief examination of the lignite areas of the county, that centers of mining are not determined by the presence of coal merely, but by the number and extent of the local outcrops, and by proximity to railroads or a market. In some instances a thin seam of lignite is being vigorously and successfully worked because the place has been favorably known and resorted to for years before other more promising seams were opened.

Natural outcrops due to undercutting and slipping along the bluffs of the streams are so common that few attempts have been made to find the lignite by extensive surface prospecting. The fact that many wells pass down to the seams has left the impression, however, that, if desired, lignite in paying quantities may be found underlying almost any part of the county. So far as can be learned, systematic prospecting, except in a few noteworthy instances, has not been carried on far from the valleys of the Mouse and Des Lacs rivers.

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* Upham, Glacial Lake Agassiz, p. 529. Darton, Preliminary Report on the Artesian Wells in a Portion of the Dakotas.

It may not be out of place at this point to call attention to some of the reasons why the outcrops are absent from areas where only a very limited continuity of the well known seams would call for their presence. The most noteworthy instance of this kind is the Mouse valley, above Burlington. Lignite, presumably from the same seam as at Burlington, is mined on the river opposite the Davis mine, and also in one place four miles below Minot from a lower seam. One outcrop that may possibly be the same as at the Davis mine, has been reported from a point a few miles above Burlington on the Mouse river. The absence of more numerous outcrops in this vicinity and from the valley in general is probably due to the fact that a large amount of drift is deposited in it, both bluffs being faced with till, sand and gravel to a depth that would easily mask all traces of lignite. In only a few places has the wash from the slopes laid bare the natural clays. The presence of the drift is further in evidence by the contrast in the angles of slopes in the two valleys of the Mouse and Des Lacs rivers. The slopes in the Des Lacs valley are steep and their faces entirely bare for miles without a break, so that lignite seams may be readily followed; while, on the contrary, the slopes at corresponding points in the Mouse valley are very gradual, and their contour makes it obvious that to find the lignite, if it exists, it would be necessary to pass through from twenty to 200 feet of drift. Traces of lignite were found in a well six miles north of the bend in the river east of Carpio. Whether the material found was but a fragment of drift coal or a part of a seam could not be ascertained. The well was near the mouth of a small coulee about forty feet above the valley bottom. One other outcrop was reported from a point opposite Foxholm.

The presence of much glacial material in the valley of the Des Lacs between Foxholm and Carpio, may also account, in part, for the lack of extensive outcrops there. Another explanation may be found in the fact that the seam which is extensively mined between Minot and Foxholm has passed below the floor of the valley, at a depth of from fifty to seventy-five feet.

Aside from conditions which prevent the outcrop of seams of lignite where they really exist, the lack of continuity and rapid thinning of seams is a very common occurrence. When one considers how delicately balanced are the conditions favorable for the formation of the lignite, it does not seem remarkable that so many beds have so slight a lateral extent. The wide areas over which the lignite occurs must have been covered with a dense mantle of vegetation, lying so near the water level that a very slight change in the surface elevation would bring the mass below the water, there to protect it from normal decay. Much of the material may have been subject to dry decomposition also, and for that reason would fail of carbonization. After long periods of such favorable conditions, an uplift of the surface took place, subjecting the area to erosion. Channels were cut deeply into the clays, removing the lignite at many points. All such places would appear today as interruptions of the seams. Such erosion continued long enough brought about base-leveling and consequent removal of entire seams over wide areas. Could the material which was removed by normal processes of erosion in Ward county, previous to the deposition of glacial drift, be restored to its natural position, raising its surface to a level as great as that of the Turtle mountains, at least, literally thousands of square miles of valuable lignite seams would be replaced with the clays. Not only has the surface been lowered by early Tertiary erosion from 500 to 1,000 feet,* but, as a part of the very process of such base-leveling and erosion deep channels must have been cut into the strata now remaining.

It is generally assumed that the strata bearing lignite, the Laramie, are practically horizontal. This assumption seems to be fully warranted by observations so far made in the county. It follows as a consequence that from 600 to 1,500 feet of lignite bearing clays have been stripped from the area of which the county is a part. Sentinel Butte is 3,100 feet high, with the Laramie series extending practically to the top. Sentinel, Square and other high buttes probably represent a base level. Buttes having a height, as many of them do, of 2,400 feet or thereabouts, represent another base level, as the larger part of the county has an elevation of less than 2,000 feet. The larger part of the lignite of the county, then, has been cut away, and the part now worked, especially in the eastern half, is a remnant only, and contains the lower seams of the Laramie formation.

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* Upham, Glacial Lske Agassiz, p. 103.

The question of quality of the lignite in the upper and lower seams has been repeatedly raised. The analyses show no special gain in fuel value for the lower seams. Neither do the physical characteristics warrant the belief that the lower veins are necessarily the best. Some of the very hardest and best lignite observed occurred in a seam at an elevation of 2,000 feet, along the Missouri, 300 feet above the seams in which most of the mining in the county is done. The chemical analyses furnish no basis for the supposition that coals in the eastern part of the county are better than those of the western. An examination of the tables will show that in some of the mines west of the county line the per cent of carbon is high and the ash low.

In some of the openings along Shell creek, the lignite has a very brown, woody appearance, showing the structure of tree trunks. From one outcrop wood, but very slightly altered, was taken from the center of the seam. The presence of this very imperfectly carbonized lignite cannot be attributed to a thinness of cover, for lying above it in elevation in the immediate vicinity, are lignites which are dark and hard, showing very little trace of woody structure.

The Elevations of the Seams at the various mining centers, only approximately obtained, are shown in the following table. In several cases, the range in elevation includes more than one seam. At one point on the Indian reservation below Elbowoods, eight seams of fair thickness were noted in a butte less than 100 feet high. The elevations are only estimates based on the known altitudes of the nearest stations.

CENTERS	APPROXIMATE ELEVATIONS
Sawyer-Minot	1,500-1,630
Burlington	1,620-1,660
Donnybrook-Galva	1,740-1,800
Kenmare	1,760-1,800
Gille-Miller, west of Flaxton	1,800-1,850
Makee mine	1,800-1,850
La Roche Percee, in Canada	1,800-1,850
Indian reservation	1,900-2,000
Shell Creek	1,900-2,000
Little Knife	1,950-2,000
White Earth	1,950-2,000
Nesson	2,100
Coal Harbor	1,740-1,800
Pony gulch	1,600
Dogden butte	1,600
Stanley	1,950-2,000

Google

CORRELATION OF LIGNITE SEAMS

These elevations furnish a basis for very uncertain correlations only. The most that can be said of seams in different localities is that they lie in the same horizon. To say that one seam is continuous with another over more than a short distance, generally requires observations at many points between the given outcrops. For further discussion of this interesting topic the reader is referred to a paragraph on the nature of the lignite seam by Dr. Wilder and to plate VI.

The following statements bearing upon the relations of seams in the county may be safely advanced.

The thicker seam at Burlington has been struck at so many places that it may be said with much certainty to extend continuously from a point west of Minot to Foxholm. It probably runs below the valley level some distance below Foxholm.

A higher seam, apparently the second above the Burlington, was traced, with a fair degree of certainty, from Galva to the mine operated by the Des Lacs Coal and Brick Company, five miles north of Kenmare.

The Gille-Miller and Makee areas are at about the same level, but between the two points much of the lignite has been cut out by erosion.

Already in the detailed description of the Pony Gulch and Jones mines, it has been stated that they were in the same horizon.

Whether the thick vein west of Sawyer and Velva is continuous with the Burlington seam has not been demonstrated. There are evidences that the seam does continue, however, more deeply covered, as the heavy seam 254 feet below the surface at the New Era mine, ten miles west of Minot.

The heavy seams outcropping a mile and a half north of Fort Stevenson may be continuous with the upper one of the seams observed on Wolf creek, north of Coal Harbor.

The impossibility of close correlation over these short distances suggests that the term "coal horizon" cannot be used with great definiteness, and further points to the probability that conditions during the Laramie epoch were favorable for the deposition of lignite through a long period of time.

RELATIVE THICKNESS OF SEAMS

The thickest extensive seam in the county is probably the lowest, the thickness being from ten to sixteen feet, and the elevation not far from 1,600 feet. Seams that would be considered very thick in ordinary mining centers, six, eight and ten feet, are found at many of the higher elevations of the county. At Nesson, just over the western line of the county, in one of the highest seams, the lignite measures eleven feet. As to the horizon in the Laramie at which heavy seams occur, no definite statements are possible, as the following examples will show:

At Coal Harbor, elevation 1,740-1,800 feet, a seam measures eleven feet. Thirty miles south of Medora, on the Little Missouri, a seam fourteen feet thick occurs at an elevation of about 2,200 feet. In Sentinel Butte, 250 feet below the top, and at an elevation of 2,850 feet, a seam twenty feet in thickness extends through the butte. In drilling the Medora well before referred to, a seam of lignite twenty-three and a half feet thick was passed through at a depth of about 200 feet, or an elevation of 2,000 feet.

It is not possible to affirm that the number of seams occurring in the county at any specified range of elevation is greater than at another. Sections are at hand which show, at points examined, great variability in this respect. Between elevations of 1,600 and 1,900 feet there is a record of five seams. From 1,900 to 2,000 a series of eight seams was noted. The numbers within a range of 100 feet, for example, vary as seen at several localities along the White Earth, from none at all to five or six.

AVAILABILITY OF LIGNITE

As a rule each farmer or ranchman in the county determines which one of the various outcrops near his farm yields the best fuel with least labor, and to this opening resorts year after year, till a slip in the bluff reveals another more convenient place. The longest haul of fuel yet noticed is made from the upper Des Lacs region east of Bowbells and Portal, to openings along the big slough in the northwestern part of the county. For example, a farmer from a point twelve miles east of Flaxton prepares for a trip of two days, one of which he spends in reaching the Gille mine, nineteen miles west of Flaxton, and in loading his coal, and the other day is used in the return haul. The northern and eastern parts of the county are less favorably situated with respect to mines than other parts, unless it be the south central. As the northeastern corner of the country becomes thickly settled, a good mine along the upper Mouse valley would be a valuable property. There are some striking instances of convenience in location of lignite outcrops. In the plateau area west of the hills there are few ranchmen who do not have individual mines within a few miles of their houses. Many do not go more than a half mile for their fuel, while in one case a three-foot vein outcrops in the bank at the rear of the house. In another locality on the same creek the posts of a barn rest upon lignite. Many of these excellent seams are so far from a market at present as to be practically worthless. As the population increases, known outcrops will be worked and new ones found, until no part of the county will be without its convenient center of fuel supply.

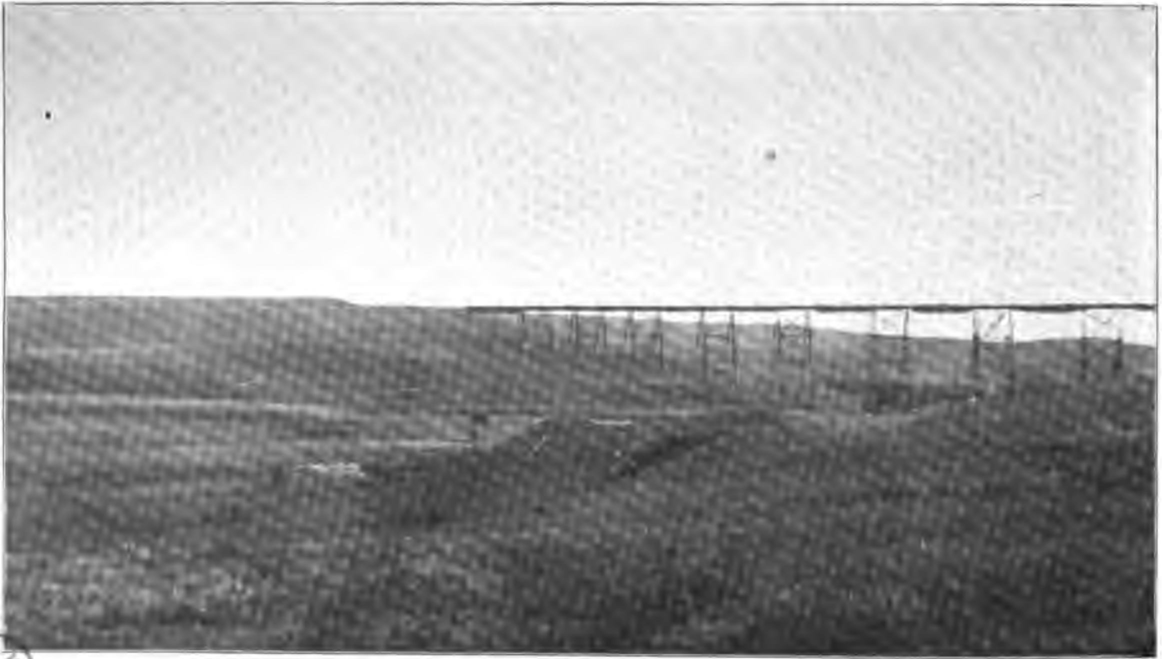
SYSTEMATIC DESCRIPTION OF THE LIGNITE CENTERS OF WARD COUNTY

The lignite industry of the county has its greatest development at Burlington and Kenmare. The lignites from these areas are the only ones widely known, and from these places the Great Northern and Soo roads carry large quantities to many places in the eastern part of the state. As the mines are grouped to a greater or less extent about certain well known points, they will be described with reference to such centers.

Lignite About Burlington.—This area begins at the Great Northern bridge, four miles west of Minot, and extends west to Des Lacs, north to Foxholm, and east to the Honeywell farm, just across the river at Burlington. Within this district twenty-two openings were noted, only a few of which can be treated in detail.

Among the more important openings in this group are the following: The Old Colton, Syndicate, Dakota Lignite and Brick Company, Mouse River Brick and Coal Company, Des Lacs Valley Coal Company, Norstrom & Rinos, Honeywell, Des Lacs and New Era.

In this area brick making is in progress an as associated industry. Most of the mines occur in the west bank of the Mouse-Des Lacs river valley, or in the lower part of the tributary coulees. The New Era and Des Lacs openings are shafts put down from the prairie level. As has already been said in



A Coulee a Few Miles North of Minot, Showing Slack Heaps from Coal Mines in the Foreground.

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another connection, it is believed that all these mines are utilizing the same seam.

The seam has an average thickness of ten feet, contains but a small amount of clay, is quite uniform in texture from top to bottom, and lies between clay seams. This center may be said to supply locally the east central part of the county, and a large amount to other parts of the state.

The Davis Mine, or Mouse River Lignite Coal Company, Township 155, Range 84, Section 12.—This mine is located one mile southeast of Burlington, on the Soo railroad, and eight miles from Minot. The entrance to the mine is about thirty-five feet above the level of the road and leads down an incline to the lignite, forty feet lower. The thickness of the seam as worked is ten feet. Below this vein, at a depth of from ten to fifteen feet, another seam three feet thick is known to exist. The seam worked has a two-inch clay seam about two feet above the bottom, and a layer of soft coal between three and six inches thick, eighteen inches below the roof of the mine. The seam varies considerably in the chemical properties of the lignite from the top to the bottom, as shown by the analyses. This mine is illustrated on plate XIX. Clay is found both above and below the coal. Between the seam now mined and the portion of the same seam worked out in the old mine a deep erosion channel, partly filled with boulder clay, exists.

The following analyses show the relative composition of the lignite from different parts of the seam:

	PER CENT
Volatile matter	35.83
Fixed carbon	51.58
Ash	11.88
Total	100.00
Moisture	32.00

Sample from the top of the seam:

	PER CENT
Volatile matter	32.60
Fixed carbon	46.42
Ash	29.98
Total	100.00
Moisture	30.00

Sample sixteen inches above the clay seam:

	PER CENT
Volatile matter	42.14
Fixed carbon	47.36
Ash	10.50
Total	100.00
Moisture	34.70

Sample from the lower twenty inches:

	PER CENT
Volatile matter	38.93
Fixed carbon	52.96
Ash	8.11
Total	100.00
Moisture	34.70

The amount of moisture, as shown by the analyses, is nearly constant. In collecting material for these and subsequent analyses, great care was taken to prevent loss of moisture up to the time of analysis, and the amount shown may fairly be regarded as indicating the amount present in the lignite as it stands in the mine.

A section from the bottom to the top of the seam appears as follows:

	FEET	INCHES
8. Clay above the seam	..	..
7. Roof of lignite	2	..
6. Upper sixteen to twenty inches of mine	..	18
5. Soft layer where miner begins work with pick	..	3-6
4. Solid lignite	4	..
3. Clay seam persistent through the mine..	..	2
2. Lignite, best in the mine	1	8
1. Clay (plastic)	..	..

A section showing the number of seams and the nature of the clay above them is shown in figure 8. Entries run back under the hill over 900 feet, and many rooms have been worked out, the mine having been in operation four years. No diminution in the thickness of the vein has yet been observed, and it remains fairly uniform in quality.

The output of the mine varies with the season, running during the summer, at from seventy-five to 100 tons per day, and 200 tons a day from September 1st to April 1st. The record of the mine shows that 5,000 tons of lignite are won from every acre mined. Miners receive for room work 50 cents, and for entry work, 80 cents per ton, experienced men earning often from $3 to $5 a day.

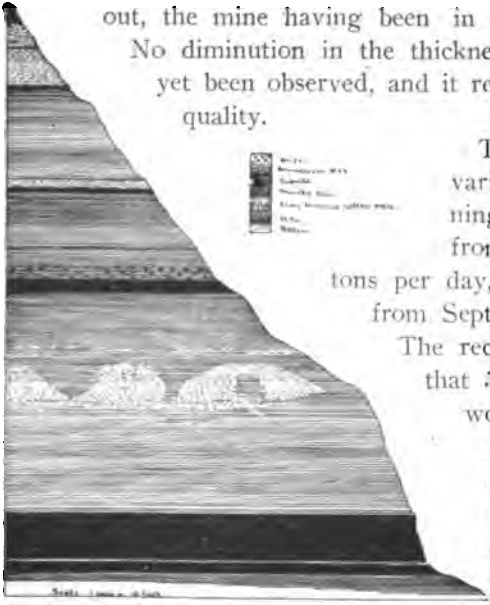


Fig. 8. Section at the mine of the Mouse River Lignite Coal Company.

The mine is worked double entry with room and pillar plan modified to overcome floor heaving. Ventilation of the mine is accomplished through forced draft, the air being driven along temporary flues at the side of the entries.

The only peculiarity noticed in the mine was a clay-filled fissure, six inches thick, running for a distance of several hundred feet. Heaving of the floor, due to the extreme plasticity of the underlying clay, makes heavy timbering necessary. In several of the abandoned rooms the floor has raised until it is now within two or three feet of the roof. The same effect is noticed in the entries.

Associated with the mining, a brick plant is operated on a large scale. It is found that 220,000 brick can be burned with 115 tons of lignite.

The Dakota Lignite and Brick Company, Township 155, Range 53, Section 10.—The property of this company is located one mile southeast of the Mouse River Lignite Coal Company's mine. By prospecting, the seam was found here to have a thickness of from ten to twelve feet, and to lie from 200 to 300 feet below the surface of the prairie. The entry had not yet been carried down to the lignite when the mine was visited, and for this reason samples are not at hand for analysis. The entry to the mine is thirty feet above the seam, which is being approached along a drift, the lower end of which is now within a few feet of the lignite. Considerable difficulty was encountered here with quicksand. Figure 9 illsutrates the position of the lignite and clay seams and the nature of the entry. Development work as shown on the surface in August, 1902, is shown in plate XX. The present mine is situated sixty rods north of the old Colton mine. Between the two mine openings there is said to be a fault that produces a difference of twenty-five feet in the elevation of the two seams. The existence of a fault at this point would be interesting, though its presence has not been demonstrated.

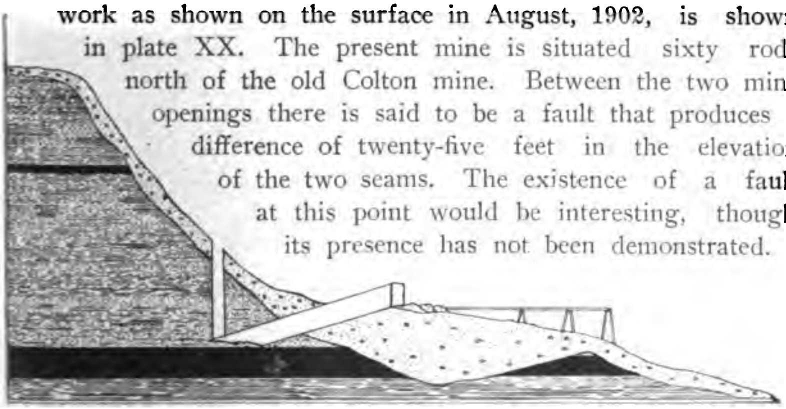


Fig. 9. Diagram illustrating relation of lignite and quicksand seams at the mine of the Dakota Lignite and Brick Company. It also shows the way in which the lignite seam is cut out by an old valley, a phenomenon observed a mile north of this mine, though not at this exact point.

The Old Colton Mine, Township 155, Range 53, Section 18. —This mine is now abandoned, though the Dakota Lignite and Brick Company will operate its mine practically in the same area. The seam was from ten to twelve feet thick here, and about sixty acres were mined out. The dip was small, so little in fact, that the mine was drained to the river by a small ditch from the entry.

Other Openings Between the Old Colton Mine and the Great Northern Bridge.—There are several openings to the same seam. Of these the one in the south bank of the coulee, thirty rods west of the bridge, shows a seam eight feet thick, with analysis as follows, lignite dried before analyzing:

	PER CENT
Volatile matter	38.01
Fixed carbon	56.57
Ash	5.42
Total	100.00

Prospecting with a drill has shown that this seam thins rapidly to the south, so that what at first might seem a good mining proposition is rendered doubtful.

Besides several other openings near the same point, whose entries have caved in, another outcrop was reported from a point two and one-half miles farther west, in the same coulee.

Des Lacs Valley Coal Company, Township 156, Range 84, Section 31.—This mine, operated by Mr. T. J. Lloyd, lies one-half mile up from the mouth of a coulee and about two miles north of Des Lacs. The entry to the mine is twenty feet above the creek on the north side of the coulee. At this level the mine is easily drained, all water being siphoned out from a sump situated back from the entry. The seam measures ten feet, and has been worked for 700 feet back into the hill.

The section at this point shows:

	FEET	INCHES
7. Boulder clay, roof	..	14
6. Lignite	..	14
5. Clay seam	..	2
4. Lignite (solid)	7	6
3. Clay seam, to bottom of mine	..	6
2. Lignite	..	16
1. Clay	..	..

The seam is not worked below the clay level, number 3, for the lower sixteen inches of lignite is of value in preventing the heaving of the floor from below.

It will be noticed that the lower clay seam corresponds in position with the one in the Mouse River Lignite Coal Company's mine. The presence of the boulder clay, not only as a roof but filling a "cutout" in the seam, is a peculiarity in this mine. A dried sample from the mine shows the following analysis:

	PER CENT
Volatile matter	33.13
Fixed carbon	58.23
Ash	8.64
Total	100.00

This mine has been in operation for several years with a total output estimated at 20,000 tons. The output at present is fifteen tons a day in summer and seventy-five tons a day in winter. Mr. Lloyd expects that the output this year will reach 10,000 tons. The value of the machinery used in operating this mine is $1,000. Seven men are employed in the summer and twenty-five in winter. Wages run at $1 a ton for entry and 70 cents per ton for room work. Ventilation in the mine is accomplished by means of an air shaft and fire. Much of the supply from the mine is shipped to Grand Forks and Minneapolis. Local trade is good, the fuel selling at the mine for $1.50 per ton.

Another opening was reported one-half mile above this one in the coulee, the seam having the same thickness. On the opposite side of the coulee from the Lloyd opening, not more than fifty rods away, no lignite has been found. One-half mile to the north, however, in a similar position in another coulee, the Norstrom & Rinos mine is in operation.

The Norstrom & Rinos Mine, Township 156, Range 86, Section 32.—The seam in this mine has the same thickness and peculiarities as in the Lloyd mine. It is ten feet thick, has the clay layers in the same relative position, and is mined in a similar manner.

Two or three men are employed here during the summer, and from ten to fifteen during the winter. About 180 box cars of twenty-five tons each are shipped from the mine annually.

Scribner Mine, Township 156, Range 85, Sections 19 and 30. —This mine lies two and one-half miles from the Norstrom & Rinos mine, and five miles below Foxholm in the Des Lacs valley. The tipple at the entrance is fifteen feet above the level of the road. The seam measures ten feet, and is so nearly horizontal that loaded cars are run by hand 400 feet from the rear of the mine to the entrance. Very little water is encountered.

For the accommodation of this mine, as well as the series of mines along this valley, the Soo line has a sidetrack. Methods of mining are of the simplest nature, due to the thickness of the seam, absence of large quantities of water and the ease with which the coal can be handled in the entries. No timbering is done in the Scribner mine, as the upper and lower portions of the seam are left in sufficient thickness to make supports unnecessary.

Analysis of dried lignite from Scribner mine:

	PER CENT
Volatile matter	36.87
Fixed carbon	51.61
Ash	12.52
Total	100.00

The Scribner mine is the last one to the north working from this seam. In a coulee between the mine operated by Mr. Lloyd and the Davis mine at Burlington, and north of the New Era mine about three miles, is the old Klondike, or People's Mining Company's claim. This mine is not now in operation. The coulee in which these mines were opened, according to the report of Mr. Houston, the former owner of the Klondike mine, contains several outcrops, showing a seam ten feet in thickness.

But one mine in the Burlington area has been opened on the east side of the Mouse river. When the place was visited in the summer, Mr. Honeywell had leased the mine to two miners who were just preparing to open the old entry. The opening contains considerable water, due probably to the fact that the mine has been idle for some months. The entry now appears to terminate at the contact of a slip with the side hill.

Two noteworthy attempts to reach the lignite of this area by shaft mining remain to be mentioned. The first shaft was sunk one mile west of the little town of Des Lacs. Here the greatest depth reached was 230 feet. At the present time the work on the shaft is discontinued, after the expenditure of $18,500. The first lignite was found at 217 feet, a three-foot seam. Under the seam, and separated from it by eighteen inches of clay, occurred a second four feet thick. One hundred and eleven feet farther down, as was ascertained by boring, lies a third seam ten feet thick, the one that is tentatively correlated with the seam at the mine along the river, six miles east. The shaft was, in September, 1902, filled with water to within five feet of the top.

An examination of the material dumped from the shaft showed that about half of it consisted of stony blue clay, or till, and the rest of bluish sandy clay from the Laramie. The stony clay, or till, contained small stones, many of which were subangular and striated. No large boulders were seen. Besides the limestone and crystalline pebbles, many fragments of lignite were imbedded in the drift.

The New Era Mine, Township 155, Range 84, Section 15.—This company is putting down a shaft three miles east of Des Lacs, on the Great Northern railroad. The bottom of the shaft in September, 1902, had reached a depth of 232 feet.

The following is a record of the shaft to date, as obtained from the superintendent, Mr. Mills:

		FEET	INCHES	TOTAL
12.	Sand, gravel and clay	40	..	..
11.	Blue clay	125	..	160
10.	Fire clay	19	..	179
9.	Lignite	5	..	184
8.	Fire clay changing to sandy soil	10	..	191
7.	Lignite	1	..	193
6.	Sandy clay	6	..	199
5.	Lignite	..	6	199½
4.	Sandy clay	15	..	214½
3.	Lignite	..	18	216
2.	Gray sand	9	..	224
1.	Fire clay	8	..	232
	Bottom of shaft at			232

Prospecting shows a seam of eleven feet and nine inches at the depth of 254 feet.

After deducting the difference in level between Des Lacs and the top of the shaft at this mine, the two numbers of this section, 9 and 7, correspond with two seams in the mine at the former place, having a depth of 217 and 222 feet respectively. The difference in elevation between these upper seams is eighty-nine feet at the Des Lacs and seventy feet at the New Era mine. Further, the depth of the eleven foot seam at these points is 254 and 336 feet respectively, or 1,590 feet above sea level. In the Mouse River Lignite Coal Company's mine, where the elevation of the seam at the entry is 1,630 feet, there is a dip of twenty-five feet to the mile southwest, which perhaps accounts for the difference in level between it and the lower seam of the New Era mine at 1,590. The following is an analysis of a sample of lignite from the New Era mine, upper five-foot layer:

	PER CENT
Volatile matter	38.22
Fixed carbon	57.96
Ash	4.12
Total	100.00
Moisture	33.06

At present, from twenty to twenty-five men are employed at $2.75 a day. There is some water in the mine, but it is easily disposed of by continuous pumping of a stream two and a half inches in diameter. The mine is the only one in the county located on the Great Northern railroad.

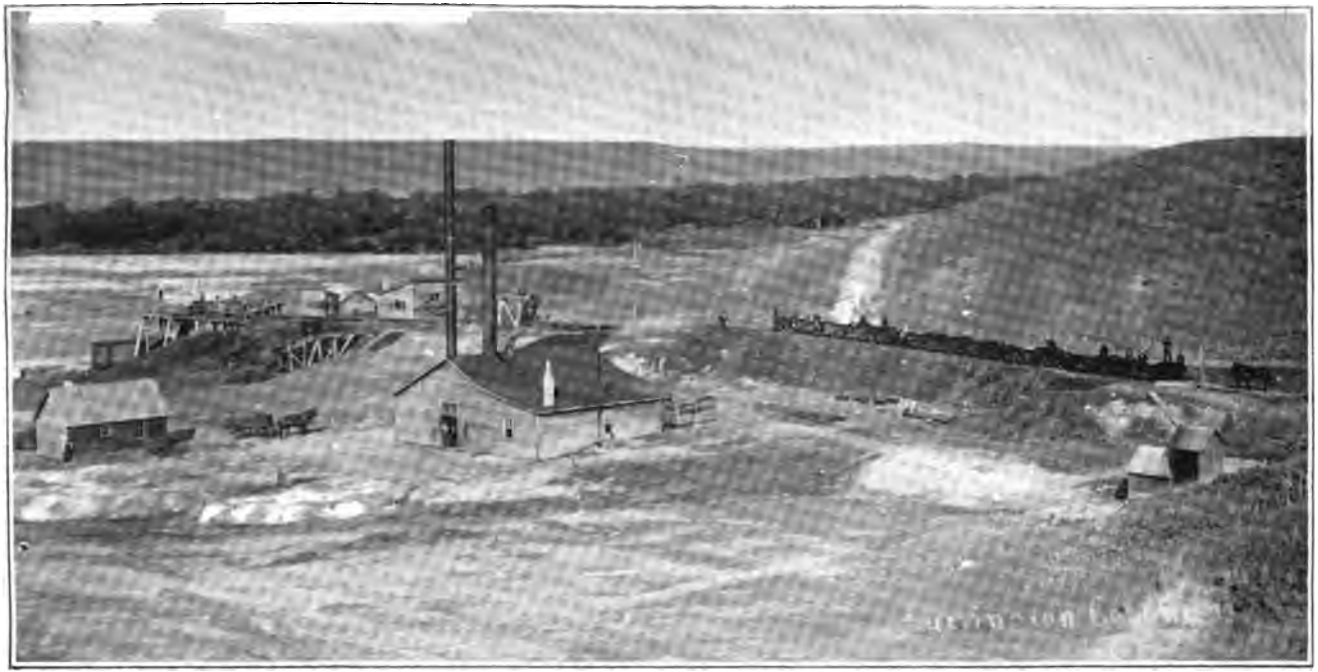
The area covered by this seam so frequently mentioned in connection with these mines in the Burlington area, if assumed to be no greater than has been determined, by the known outcrops, is almost the size of a township. The amount of lignite contained within the area, reckoning a ton to a cubic yard, is 313,344,000 tons. If 30 per cent of this coal is won from the mines, there is enough to supply the state for years to come. The amount of lignite which it is possible to remove from a mine in this section depends upon the nature of the roof and floor, 40 per cent being a high average.

DONNYBROOK-GALVA CENTER

In passing up the Des Lacs river valley, the last outcrop of what might be the Burlington seam was reported at a point one mile below Foxholm, but the bank having caved in, it was not found at the point named. Mr. Simons of Foxholm has filed a claim upon this property, and has made arrangements to operate the mine during the winter.

In the river bank one-half mile west of Carpio, a thin seam of two feet in thickness has been opened for local use. The seam lies so low, however, that difficulty with water may be encountered. The upper seam of the Des Lacs mine, elevation 1,680 feet above sea level, should begin to appear somewhere near Carpio, which has an elevation of 1,696 feet.

The Donnybrook-Galva area is noted for numerous and extensive outcrops rather than for thickness of seams. The quality of the coal from the thin seams is very good, and the number of entries from which lignite has been removed for local use is larger than in any other part of the county. No less than twenty places were found within a small area where fuel had been taken in considerable quantities, one coulee having eight openings.



The Mine of the Mouse River Lignite Coal Company at Burlington, near Minot.

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The seam has a thickness of from two to four feet here in the valley for several miles, beginning, so far as could be learned, two miles below Donnybrook, at an elevation of twenty feet above the creek level, and extending as far as Galva. Whether this seam continues into the Kenmare district has not been ascertained, since a break in exposure of several miles exists between the last opening at Galva and the first at Kenmare. The difference in elevation is not great. With but two exceptions the lignite outcrops occur in the west side of the valley. One of these outcrops on the east side of the valley was seen at Galva, and the other is now being worked by the Carroll Brothers, four miles below Donnybrook, in Township 158, Range 85, Section 28.

Mr. Carroll was not at the mine when it was visited, but from what was seen then and from correspondence since, it is learned that there are two seams separated by a two-foot layer of clay, the thickness of the lignite aggregating about four feet. The material above and below the lignite is clay, that from below being used in brick making. At present about 1,000 tons of lignite have been removed from the entry. The brick plant was incomplete in the summer of 1902. The combination of the two industries at this point on the river should be very profitable, since not only can the brick be burned at slight expense, but this is the only brick plant between Davis' mine and Kenmare.

Leigh and Ericson Mine, Township 158, Range 85, Section 5. —This mine was recently opened. The entry has been driven 100 feet into the bank, showing a seam of good quality and uniform texture from three to four feet thick. A peculiar ridge-like elevation had just been struck at the end of the entry. The following sections, A, taken fifty feet from the entry, and B, taken at the top of the ridge at the point of digging, show how the lenticular shaped layer of clay lies between the sand and the lignite:

A	FEET
Sand to top of mine	..
Clay	1
Lignite	4
Clay, bottom of mine	..
B	
Sand, top of mine	..
Lignite	4
Clay	Bottom of mine

The analysis of the dried lignite is as follows:

	PER CENT
Volatile matter	35.14
Fixed carbon	59.75
Ash	5.11
Total	100.00

The sales from this mine are mostly local.

One mile above the Leigh-Ericson mine, on the river, there are a large number of openings in the coulees from which lignite in very considerable quantities is taken during the winter by farmers who resort to these places from many miles for their fuel.

No mines were in operation during the summer between the Leigh-Ericson mine and Kenmare. Mr. Hill of Galva was driving an entry with the intention of mining there during the winter; but as has been learned later, the opening was not a success.

KENMARE DISTRICT

The Kenmare district includes the mines that are in operation between the lower end of the second lake and a point five miles north of the town on Lake Des Lacs. There are twelve openings in the bluffs along the lake, from which the output of lignite varies between a few hundred and many thousand tons annually. The seam first encountered at the Tasker coulee, between four and seven feet thick, extends the full length of the district at practically the same elevation, twenty to thirty feet above water level in the lakes.

The Smith-Kenmare mine works the seam where it lies nearly at lake level. If this seam is as continuous to the east and to the west as it is from north to south, it should be possible to reach its level on the prairie by a shaft at a depth of from eighty to 125 feet. Mining is, in general, carried on by the room and pillar method. Part of the timbering is dispensed with by using the upper edge of the lignite seam as a support for the cross pieces in the entries. In each of the mines ventilation is secured by means of an air shaft from the surface above the mine to one of the entries. Fires are kept burning under these shafts when necessary to secure circulation. The Soo road has a side track for the use of all the mines in the district except one, which.was but recently opened.

Kenmare Hard Coal Company, Township 160, Range 88, Section 32.—This company, under the management of Mr. B. B.

Tasker, operates a mine situated at the mouth of the Tasker coulee on the southwest corner of the second lake. A new electric plant for lighting the mine, and for running drills and undercut machines, with which the mine is to be equipped, will be completed during the summer. It is expected that the output during the winter months will reach 250 tons a day. From twenty-five to fifty men are employed, a part of whose time during the summer season will be used in brick making in connection with the mining. For purposes of brick, the clay under the lignite is used.

There is an older mine in this coulee, located on the north side opposite the present entry, which was abandoned on account of slipping.

Analysis of dried lignite from the mine:

	PER CENT
Volatile matter	35.89
Fixed carbon	51.06
Ash	13.05
Total	100.00

The amount of ash is probably too high to represent the average for the mine.

Silver Vein Coal Mine, Township 160, Range 88, Section 32.—This mine is located on the opposite side of the coulee from the Kenmare Hard Coal mine, with its entrance facing the lake. An air shaft was being made at the time the mine was visited. From three to twenty miners are employed, and the output varies from five tons in summer to fifty tons per day in winter. This mine, as well as the others in the coulee, are so conveniently located with reference to roads that the properties should prove to be very valuable. Mr. Swartz, the operator of the mine, owns 167 acres here.

Diamond Mine.—This mine is situated one mile below Kenmare on the east side of the lake, and has its approaches directly on the railroad. Its output is about 100 tons a day during the fall and winter. The company runs its lignite to a large coal shed, where it is dumped directly into box cars. The mine is worked double entry, room and pillar system. The walls are firm and no serious difficulty is experienced with water. A considerable area has been worked out, as is shown by the large quantity of coal shipped from the mine. The seam has a thickness of five feet, dips at the entry through a vertical distance of eight feet until the floor of the mine is reached, where it remains horizontal.

Analysis of the lignite shows the following constituents:

From the top of the seam:

	PER CENT
Volatile matter	37.24
Fixed carbon	52.98
Ash	9.78
Total	100.00
Moisture	33.00

From the center:

	PER CENT
Volatile matter	33.77
Fixed carbon	56.82
Ash	9.41
Total	100.00
Moisture	33.00

Eighteen inches from the bottom:

	PER CENT
Volatle matter	36.38
Fixed carbon	56.97
Ash	6.75
Total	100.00
Moisture	33.60

Hart Mine.—This mine, but recently opened, is situated three-quarters of a mile below Kenmare, adjacent to the Diamond mine. The entry has been carried in about 100 feet, showing a vein that measures four feet, dipping slightly to the east for the first forty feet in the entry and then raising again at about the same angle. An abandoned entry near this one shows that boulder clay was encountered.

Smith-Kenmare Mine, Township 167, Range 88, Section 7.—The Smith-Kenmare mine is located two and one-half miles north of Kenmare on the east shore of Lake Des Lacs. The mine is approached by a road running along the lake front, and by a spur from the Soo railroad. The output from this mine is largely shipped to points beyond the county, but local trade consumes a considerable amount. The output for the period May 1, 1901, to June 1, 1902, was as follows: Local, 2,000 tons; shipped, 4,500 tons. Work is carried on continuously during the year, though during the summer repairs in and about the mine consume most of the time of the employes. Thirty men are worked from September 1st to March 1st, or about seven months out of the year.

The seam of this mine averages six feet, is quite uniform in texture from top to bottom, presenting faces of solid lignite at all points. There is some variation in chemical composition as shown by the following analyses:

Sample from next to clay above the lignite:

	PER CENT
Volatile matter	36.78
Fixed carbon	55.55
Ash	7.67
Total	100.00
Moisture	33.20

Sample from point next to roof:

	PER CENT
Volatile matter	39.90
Fixed carbon	52.30
Ash	7.00
Total	100.00
Moisture	32.00

Sample from one foot below roof.

	PER CENT
Volatile matter	33.50
Fixed carbon	55.25
Ash	11.25
Total	100.00
Moisture	32.60

Sample of thin section in seam, selected because of its peculiar hardness:

	PFR CENT
Volatile matter	33.41
Fixed carbon	61.24
Ash	5.35
Total	100.00
Moisture	33.60

The mine is worked by the room and pillar system, with ventilation obtained by an air shaft. The per cent of coal won from this mine is large, due to the firmness of the walls. The material above the seam is a very compact clay. It contains no grit and is said to be a good potters' clay. This company has other openings, not yet worked, between its present mine and Kenmare.

Electric Mine, Township 160, Range 89. Section 12.—The Electric mine is situated directly opposite the Smith-Kenmare mine on the Des Lacs lake. The mine is but a few rods distant from the main track of the Soo road, from which a spur is built. The past summer was partly consumed in the installation of the electric plant, which furnishes not only light for the mine, but power to the drill and undercut machines. One Morgan-Gardiner undercut machine is now in use, which will undercut the lignite, removing material from a space six feet wide, four feet long and five inches thick, in three and one-half minutes. Four more of these machines have been ordered. The outside equipment is sufficient for an output of 500 tons of lignite daily, but during the summer one carload only, mainly from the entries, was the extent of the output.

The seam measures between four and seven feet at this point, and shows a fairly uniform grade of lignite from top to bottom, as appears from the results of analyses, which are as follows:

Sample four feet above floor:

	PER CENT
Volatile matter	34.41
Fixed carbon	57.95
Ash	7.64
Total	100.00
Moisture	32.90

Sample three feet above floor:

	PER CENT
Volatile matter	36.56
Fixed carbon	59.19
Ash	4.25
Total	100.00
Moisture	35.00

Sample from bottom:

	PER CENT
Volatile matter	34.44
Fixed carbon	56.58
Ash	6.98
Total	100.00
Moisture	35.10

Sample from top of seam:

	PER CENT
Volatile matter	36.58
Fixed carbon	56.87
Ash	6.55
Total	100.00
Moisture	34.80

The moisture represents practically the full amount in the lignite as it stands in place in the mine. After exposure to the air for three weeks it falls to 15 per cent. This is true of lignites throughout the state.

This mine is worked double entry, and room and pillar, and ventilation is secured by a continuous fire at the base of an air shaft. The mine is comparatively dry, as but twenty barrels of water are pumped out in a day. In running the entry to this mine, a slip of twenty feet, with slickensides, was struck. (See figure 7.) The present mining is done twenty feet above the floor of the outside entry, and the loaded cars in their descent draw the unloaded to the top of the grade. The slip in this mine is a type of a very common occurrence in the mines along the river. Plate XXII shows the power house of this mine.

Fleckteen's Mine, Township 161, Range 88, Section 31.—The Fleckteen mine is situated one and one-half miles above the Electric on the same side of the lake. Work so far has been done largely on the entry, which shows the same effect of slipping as occurs in the Electric, and also in the old Kenmare Hard Coal mine. One man is employed during the summer and four or five during the winter, with an output of about ten tons a day. The thickness of the seam is from four to six feet. The mine is naturally drained to the lake, but a pump is soon to be put in operation. An air shaft in the hill furnishes ventilation. Several other old entries appear near this mine on the lake front.

Evans Mine, Township 161, Range 88, Section 30.—This mine lies one mile above the Fleckteen mine on the same side of the lake. It has been in operation from September to January for the past four years. The annual output is from 1,000 to 3,000 tons, much of which supplies local trade. A new entry is being made and other preparations for a heavy fall and winter run. The mine is one-half mile from the Soo road, where a side track is provided for the use of this and other mines at this part of the lake.

There are two seams here, separated by a stratum of clay, one measuring three feet and the other five feet four inches.

Des Lacs Coal and Brick Company.—This mine was the last one examined on this side of the river. The seam at this point measures five and one-half feet, with a roof and floor of sandy clay. The mine is comparatively dry, as the water can be removed from the sump at the entry by operating the engine pump a few minutes at a time as often as once an hour. It has as yet no ventilating shaft. The work is carried on by room and pillar method. The mine is furnished with a stationary engine, which will, in addition to the mine work, supply power for a brick machine as soon as it is ready for operation. Dump from the mine is carried by a track to a tipple on the lake front.

Smith-Jones Mine, Township 161, Range 88, Section 29.—This mine is located five miles above Kenmare on the east side of the lake. The operators have arranged, by the use of a stationary engine, to hoist their lignite on an incline from the mine at the foot of the hill to the level surface above, for the convenience of their customers. The neat little plant, costing about $2,500, promises to have a very considerable business during the winter. Four men are employed at present, and more help will be hired in the fall. The output during the summer of 1902 was five tons a day.

The main entry has now been carried back 300 feet under the hill. The seam of lignite here measures four feet six inches, with clay above and sandy clay below. The trade is mostly local, as the mine has no connection with the railroad as yet.

The following is an analysis of a direct sample from this mine:

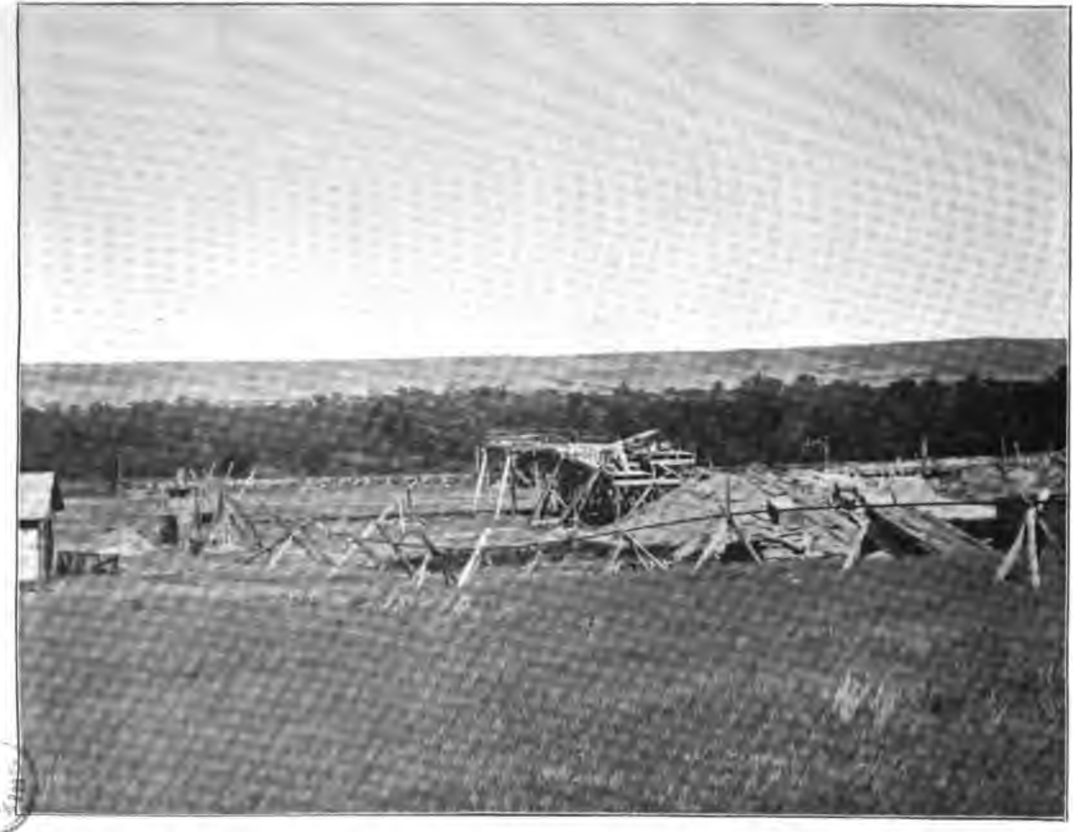
	PER CENT
Volatile matter	35.43
Fixed carbon	51.16
Ash	13.41
Total	100.00

Other analyses which represent the mine more fully are given in the chapter on "Fuel Values of the Lignites."

One outcrop, from which some lignite is removed during the winter only, was reported above this point on the lake. Other mines will doubtless be put in operation further up the lake as the local demand for fuel increases.

THE GILLE-MILLER CENTER

In the north central part of the county, above the Kenmare area, few if any outcrops of lignite have been reported, though its presence at some depth is shown by wells. At Bowbells a seam of lignite was struck at 102 feet. Two and one-half miles north of the same place a four-foot seam is reported at forty feet, and eight miles farther north one at eighty feet. Eight miles southwest of Flaxton, lignite is reported at a depth of twenty-two feet, and one mile north of the boundary, in the vicinity of



Development Work at the Dakota Lignite and Brick Company near Burlington, August, 1902.

the Makee mine, at twenty feet. In general, wells that penetrate far into the Laramie clay pass through several seams of lignite of variable thickness.

Paying quantities of lignite that can be conveniently worked with simple appliances are restricted to the northwestern part of this portion of the county. The most productive belt of mines or outcrops lies along a bench two to five miles north of the hills and running parallel with them; and in an extension of the bench to the north, along the creeks that drain the area to the Mouse river in Canada, some good mines are found. The belt probably extends far over into Williams county. Besides eighteen outcrops actually visited, several others were reported on good authority from within the area. It is also probable that lignite will be found at many new points along the edge of the hills and in the valleys of the creeks, and very shallow prospecting would probably be repaid by the discovery of heavy seams in convenient locations. Due to the very abundance of the local openings and the great distance from a railroad. the extensive supplies of fuel from this area will probably not be worked in a systematic way for some time to come.

The outcrops here, as in the Des Lacs valley, are due to stream work. The small creeks that flow to the sloughs pass nearly at right angles across the bench-like remnants of the Laramie, which project from beneath the hills, and the lignite is revealed at almost every pass. The map of this county shows this bench facing the sloughs, and the streams cutting through it from the south. Toward the east the bench merges into the rolling, drift-covered section west of Bowbells, and outcrops were not seen nearer than ten miles of that place. Outcrops are also reported from points south of the bench in the coulees where streams are cutting back into the hills; this is where the lignite should be found.

At every one of the outcrops shown on the map, excepting the one in the hills, which was not seen, quantities of lignite varying from a few loads to hundreds of tons have been removed. In no case does the seam lie more than forty feet below the surface of the bench or creek bank, while in several it lies practically on the surface, or can be laid bare by the removal of a few feet of dirt. The opening shows a good grade of coal where it has not been too much weathered. The various outcrops of the section will not be described in detail, since they are fairly well represented by the two mines which are regularly worked, and which are described in the following paragraphs.

Gille-Miller Mine, Township 162, Range 93, Section 20.—This mine is located eighteen miles west and four miles south of Flaxton. The claim was owned and operated some years ago by Mr. Gille, but is now in the joint possession of Mr. Gille and Mr. Miller, while the pit is leased to Mr. Booth, who is both manager and miner. Lignite is sold at the mine for 80 cents a ton, to farmers who load their wagons from the loosened material. The mine has a good name, and its reputation is due partly, no doubt, to the fact that the seam lies so conspicuously on the surface. An eleven-foot seam is exposed by the removal of a few feet of clay with the scraper. Wagons are backed down upon the lignite surface, the bottom of which has not yet been reached in the pit. The seam has been partly burned out, forming a gulch-like opening an acre or two in extent, that contains a very dangerous quicksand bog. Grass covers the hardened places in this bog, but numerous holes occur filled with a watery mixture of clay and ashes, where a horse or man will sink out of sight. The bog is due to the drainage from the rim of lignite that partly surrounds it.

No difficulty is met in mining except that water settles down in the pocket between the slightly inclined surface of the coal and the clay bank, but this is easily removed by using a pump for half an hour a day.

The analysis of a dried sample from the mine is as follows:

	PER CENT
Volatile matter	34.19
Fixed carbon	60.12
Ash	5.69
Total	100.00

The analysis from the opening called the Sorensen mine, Township 162, Range 92, Section 32, is as follows:

	PER CENT
Volatile matter	34.12
Fixed carbon	60.95
Ash	4.93
Total	100.00

Several other openings near the Gille-Miller mine have locally a very good reputation for the quality of their lignite.

Openings from which the thickness of seam is taken partly on report are as follows:

Paul Shurman, claim adjacent to the Gille-Miller mine. Seam four to six feet.

Catrina Vick, claim one mile west of Gille-Miller mine. Seam four to six feet.

E. R. Domrosse, Township 162, Range 93, Section 29.

S. Messinger of Bowbells, on Township 162, Range 93, Section 29.

Several openings here show the seam to be from three to five feet thick, lying from seven to twelve feet below the hill level.

On Township 161, Range 91, Sections 6 and 1, a vein of lignite was reported as eight feet thick.

Beavert mine, Township 161, Range 91, Sections 6 and 1, seam six to eight feet thick.

Opening on Township 162, Range 91, Section 35, seam eight feet thick.

Opening on Township 162, Range 91 Sections 4 and 27. Reported to be poor. but the seam is probably surface weathered.

Makee Brother's Mine, Township 164, Range 93, Section 31.—This mine is located about ten miles west of Portal, in Short creek, twenty rods south of the international boundary line. It has been operated by the Makee Brothers of Portal since July, 1900. As at the Gille-Miller mine, one man can do all the work necessary for the summer output, while more help is employed during the fall and winter.

The entry of the mine is ten feet above water level in the creek and the same distance below the prairie surface. The overburden increases in thickness to the west of the creek valley, becoming as much as thirty-seven feet some distance from the entry, as shown at the air shaft.

The seam is here broken by two clay layers a few inches thick, the lignite aggregating five or six feet in thickness. Light timbering is necessary, and mining is carried on in room and pillar style. The vein is found to dip down toward the southwest. The area mined out shows that a large amount of coal has been removed.

The Makee mine is situated ten miles north of the Gille-Miller mine, and about six miles south of the Roche-Percee mine, in Canada. Outcrops occur along the north-south line at many places, but it is at present impossible to correlate the seams represented, because no definite elevations have been determined in the western part of the county. The several outcrops along Short creek south of the Makee mine show a good quality of lignite. A seam is struck in a well at twenty feet, one mile from the boundary north of the Makee mine, presumably the same seam.

MINES SOUTH AND SOUTHEAST OF MINOT

At the present time the southeastern part of Ward county is not well known as a mining center, though it is safe to say that before the winter has passed a rather large amount of lignite will be removed from the area. Reports of lignite have come in from nearly every one of the large coulees tributary to the Mouse in this area, but so far it has only been seen in but four places. Its occurrence in these few places, however, is of such a nature as to render likely its presence in others. All of the outcrops except one were found on the west side of the Mouse river.

In the broad prairie, for a distance of from twelve to fifteen miles west of Sawyer and Velva, the streams have cut their way back to the foot of the hills. The lignite outcrops observed were between three and four miles from the hills in the upper part of these coulees, where they are from forty-five to seventy feet below the prairie level. In the case of the Hanchette mine, the elevation above the bottom of the draw was about fifteen feet; in the Turtle Gulch mine, the bottom of the seam was at creek level. The De Pue opening was not seen, but it lies, presumably, in a similar position. The covering of the seam is boulder clay, a fact which leads to the inference that the natural clay overlying the coal was entirely eroded away by waters or ice, or both, and the till deposited in its place. Whether much of the lignite was carried away with the clay cannot be determined, but the thickness of the seam remaining is considerable. In passing to the north in the direction of Minot, the seam apparently lies under a greater cover of material. If correlations could be trusted, it would be safe to say that the depth of the covering increases gradually from forty-five feet, in Township 151, to the north, as far as Des Lacs, where it is 336 feet. Little mining has been done in this area so far, and that for local use only.

Hanchette Mine, Township 152, Range 81, Section 29 (see plate XXIII).—This opening has been leased for the season, and work in stripping the surface had begun when the mine was visited. The seam measures eleven feet here, the lower eight feet being solid coal, while the upper three feet is more or less weathered. At the point where mining is begun, the cover has a thickness of ten feet, consisting of boulder clay. The following is the analysis of a dried sample of the lower eight feet:

	PER CENT
Volatile matter	40.14
Fixed carbon	53.60
Ash	6.26
Total	100.00

Turtle Gulch Mine, Township 152, Range 82, Sections 11, 15, 2.—The opening is situated eleven miles from Velva, and between seven and eight miles from Sawyer. It is seven miles north of the Hanchette mine, and two miles northwest of the De Pue opening. It is probable that these openings all represent the same seam.

The outcrops of the Turtle Gulch mine extend for a mile or more along the coulee, at a depth of seventy feet below the prairie level, with a covering of boulder clay. At the point where the mine will be operated, there are four large entries that show a thickness of from eleven to fourteen feet of lignite. From these openings thousands of tons of lignite have already been removed, for mining has been carried on intermittently for fifteen years. The vein is practically solid, no soft coal or clay seams appearing anywhere. Some of the openings are so large that a wagon can be backed into them to be loaded. A sample shows the following analysis:

	PER CENT
Volatile matter	37.20
Fixed carbon	53.78
Ash	9.02
Total	100.00

The reported outcrops from the De Pue mine, and also from an opening in the State University land, in Township 151, Range 81, Section 1, are said to show similar conditions, both in respect to position and to thickness of seams.

The area worked in this outcrop is not less than a township, and accordingly the district ranks with those of Burlington and Kenmare in the amount of lignite contained. The only disadvantage of mining here as compared with the latter areas is the comparatively long distance from the railroad.

Other outcrops at greater depths in the coulees northwest of these mines were reported at points to within four miles of Minot.

Reishus Mine, Township 154, Range 82, Section 33.—This mine, four miles below Minot, is one of the very few outcrops noticed on the east side of the Mouse river. The seam, with a thickness of between two and three feet, lies exposed eight feet above low water on the bank of the Mouse river. Lignite is removed on demand at all times during the year, the total output being considerable. The mine has been in operation about 1 year.

LIGNITE ON THE MISSOURI AND ITS TRIBUTARIES IN WARD COUNTY

The area here discussed is equivalent to that part of the county referred to earlier in the report as the plateau belt. It includes the valleys of the three streams—Shell creek, Little Knife river and White Earth creek—lying within the county, and a small area in Williams county in the vicinity of Hofflund and Nesson, together with the north bank of the Missouri river frem Nesson to Fort Stevenson reservation. Lignite bearing clays are more exposed in this area than east of the hill, and consequently furnish a large number of outcrops which are so abundant that the casual observer might be excused for carrying away the impression that the whole region is underlain with a half dozen seams of coal. But aside from a few cases the thickness of the seams represented by the outcrops is not greater than the average.

The bluffs along the Missouri bounding this area on the south are between 300 and 400 feet high, and, as would be expected, show the longest continuous exposures of lignite seams. The valleys of the tributaries of the Missouri are cut in the horizontal strata to a depth of from 100 to 300 feet, and have bare, steep faces that are also extremely favorable for outcrops. The undercutting that loosens the clay in the banks at the same time undermines the seams of lignite, thus preserving the fresh appearance. In the following outline only a few of the numerous openings can be mentioned and these very briefly. No extensive or continuous mining is carried on in this area, so far as known.

Shell Creek Valley.—The first mine found here, near the head of the valley, had the attractive name of Pleasant Valley Coal mine. An office building sets off the otherwise bare site and gives to the place a business like appearance. The seam is located in a coulee one mile from the main valley, in Township 155, Range 89, Section 30. The bottom of the seam lies at the level of the creek. Six feet of lignite are in sight, and it may extend two or three feet further down. The roof is of clay, interbedded with coal, while a clay seam runs through the lignite eighteen inches from the top. Lignite is taken for local use. A dried sample gives the following analysis:

	PER CENT
Volatile matter	39.89
Fixed carbon	55.09
Ash	5.02
Total	100.00

From the woody, brown appearance of the coal it was not expected that the analysis would show so high a per cent of carbon.

Five miles farther down the creek, in a similar position in another coulee, is another outcrop with about the same dimensions and characteristics. In this case, as in the one above mentioned, the lignite had been laid bare by lateral cutting of the creek. One peculiarity of the last named outcrop was the fact that its roof was at one end Laramie clay, and at the other boulder clay containing fragments of lignite.

Analysis of a dried sample from this opening in Township 154, Range 88, Section 33:

	PER CENT
Volatile matter	39.41
Fixed carbon	57.52
Ash	3.07
Total	100.00

The school section, four miles below the last outcrop, in Township 153, Range 88, Section 16, facing the main valley, was mined for lignite during the past winter, as shown by the opening.

Other openings were noticed at the following points:

On Guy Frank's ranch, Township 153, Range 89, Sections 28 and 29.

At Sanford's ranch, Township 153, Range 91, Section 28.

At Foster's ranch, Township 153, Range 90, Section 17.

Much lignite is reported from the west fork of Shell creek.

Little Knife River.—The outcrops along this stream though numerous showed no great thickness. Near Mr. Sikes' ranch, ten miles south of Stanley, a seam of seven feet was reported, though a slip so obscures the outcrop that the seven-foot face was not seen. A seam twenty inches thick was struck in

Mr. Sikes' cellar. A specimen from it gave the following analysis:

	PER CENT
Volatile matter	42.68
Fixed carbon	47.55
Ash	9.77
Total	100.00

Between Mr. Black's ranch at the mouth of the Little Knife and Mr. Sikes' ranch the following outcrops were noticeable either for their thickness or for convenience of position:

Township 153, Range 92, Section 22. The seam appears at the level of the creek, showing from two to three feet of lignite.

Township 153, Range 92, Section 19. On David Hawkins' ranch, a seam forty feet above the creek shows from two to three feet of lignite.

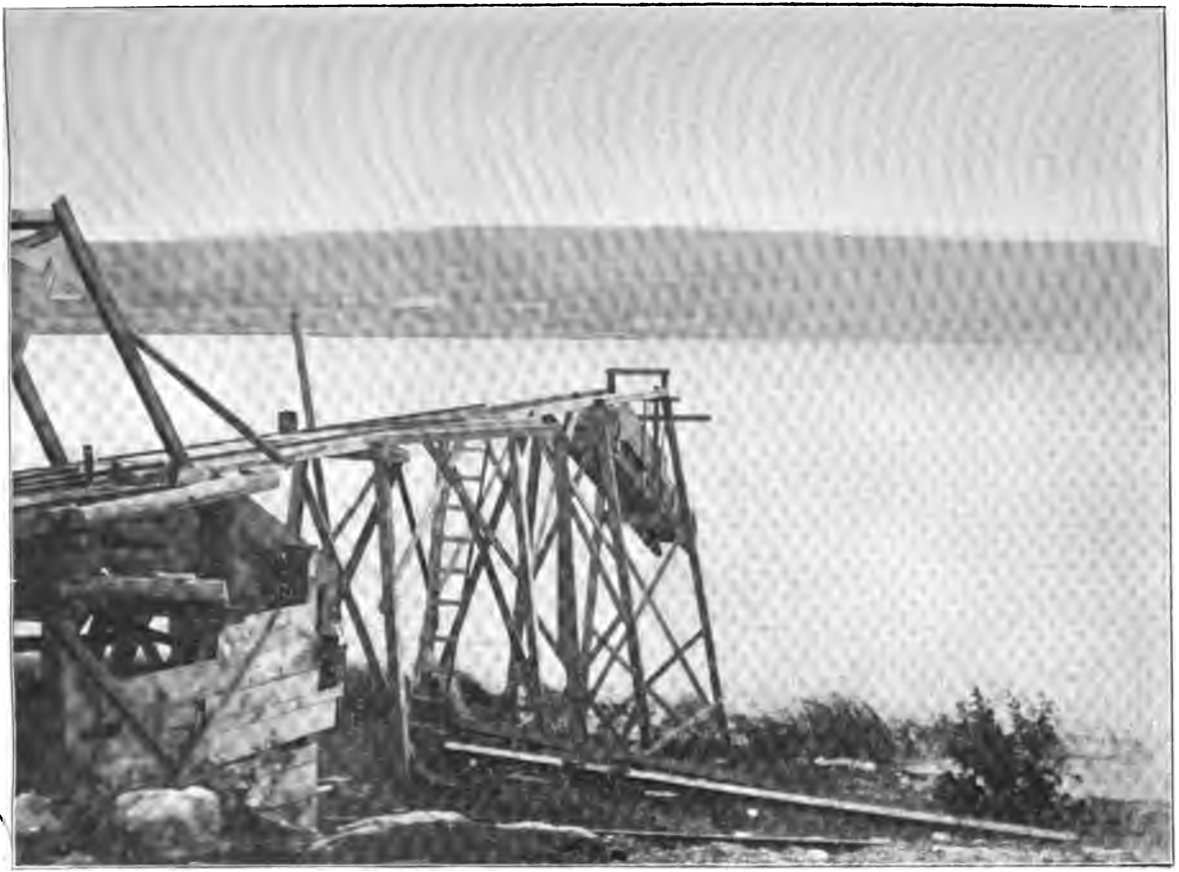
One mile up the valley from Mr. Hawkins' ranch a seam three feet thick outcrops at the creek level.

Mr. Gibbs, located on Township 154, Range 92, Section 31, obtains his fuel from the hills near by, where the seam is three feet thick.

Between Mr. Gibbs' and Mr. Sykes' ranch, the lignite outcrops in several places, but no seam of greater thickness than three feet was seen.

Anderson Mine, Township 155 Range 92, Section 13.—Half way between Mr. Sykes' ranch and Stanley, the presence of a seam of fair thickness and convenient surroundings gives promise of a considerable mining activity for the future. Two claims have been filed on mining land near this point, one by Mr. Anderson of Stanley and the other by Mr. Alger of the same place.

The Anderson mine lies about four and one-half miles south of Stanley, on the west side of the valley. In September a seam measuring six feet had been uncovered, with indications of a greater thickness. The point is well chosen for a mine, inasmuch as it lies at the edge of a draw nearly on a level with the road, about thirty feet above the river. The approach is easy, and water will occasion little if any trouble.



Tipples of the Smith-Kenmare Mine.

LA. OF MICH.

Mr. Alger's mine lies in a similar position in another draw. The following is the analysis of a dried sample from the Anderson mine:

	PER CENT
Volatile matter	38.40
Fixed carbon	50.95
Ash	16.65
Total	100.00

Sample from the Alger opening:

	PER CENT
Volatile matter	35.57
Fixed carbon	49.63
Ash	14.80
Total	100.00

White Earth Creek.—White Earth creek flows due south for thirty-two miles, with a fall of between seven and ten feet per mile. Its valley furnishes a range of 300 feet in the elevation of the seams of lignite. No remarkable thickness of seam appears anywhere, but almost every outcrop would furnish lignite in paying quantities were it near a market.

The map of the county shows the approximate location of the outcrops.

But few claims have been filed in the valley, as the demand for the lignite is small, each ranchman having his own mine.

Paul Renwle has a claim four miles north of White Earth, and it is reported that there is a claim filed on openings one and a half miles, and again at eight miles above the same place.

Analysis of a dried sample from an opening eight miles north of White Earth in the valley, from a point one mile southeast of O. Johnson's ranch:

	PER CENT
Volatile matter	36.94
Fixed carbon	56.51
Ash	6.55
Total	100.00

A good sized spring issues from this mine, but its position above the creek would permit a ready drainage. The same seam outcrops at several places near by, and two other seams of small dimensions appear above it. Other outcrops appear at several places between Renwle's mine and White Earth.

In the valley south of White Earth, from an opening on the school section in Township 156, Range 94, Section 16, some loads of lignite have been removed. Further down, on Sections 21 and 22, Mr. E. T. Williams has opened a seam that shows a thickness of from four to five feet. A large stream of water, which must occasion some difficulty, flows away from the mine. Otherwise mining here would be easy, since the seam is overlain with but a few feet of clay and is easy of access. The same vein outcrops at several places within a half mile of this opening.

Analysis of dried lignite from the seam opened by E. T. Williams:

	PER CENT
Volatile matter	31.59
Fixed carbon	44.49
Ash	23.92
Total	100.00

Two miles farther down the stream, Mr. M. S. Williams has several places from which he may take his fuel, one seam having a thickness of eight feet. A three-foot seam was discovered in digging a root cellar about sixty feet from his woodpile, by the house. Four miles below this point, in the vicinity of Mr. Boyd's ranch, several openings occur where the seam is five or six feet thick.

The outcrop from which Mr. Boyd gets his fuel shows the following analysis. Lignite dried before analyzing:

	PER CENT
Volatile matter	37.85
Fixed carbon	55.18
Ash	6.97
Total	100.00

This opening is situated in Township 155, Range 94, Section 27. At this point two seams outcrop, the lower being five feet thick, the upper, ten feet above, three feet thick. The hill rises 200 feet above the coal. The clay below the lignite is a fine grained, light gray clay, similar to the clay seen in so many of the mines along the Des Lacs valley. The top layer is also clay, and just at its lower face lies a thin seam of pyrites of iron and gypsum. The last named substance occurs at many of the outcrops and in a similar position. A mile and a half above this point, on the creek, in Township 155, Range 94, Section 15 or 16, at about the same level, a seam shows the following section:

	FEET	INCHES
9. Yellow clay	20	..
8. Bluish clay	3	..
7. Compact yellow clay	..	10
6. Lignite	..	10
5. Yellow clay	..	10
4. Lignite	2	..
3. Light gray clay	..	5
2. Lignite	5	..
1. Clay to creek level	8	..

The seam below Mr. Boyd's ranch passes through the hill and reappears in the next bend on the stream, a half mile farther down in a direct line, as Mr. Gilman's mine.

Hofflund, Nesson, Beaver Creek.—On Beaver creek, three miles above Hofflund, there is an opening from which a local supply of coal is drawn.

The analysis of the Beaver creek sample shows it to be of very fair quality and low in ash. Dried before analyzing:

	PER CENT
Volatile matter	38.34
Fixed carbon	57.97
Ash	3.69
Total	100.00

This mine is situated in the north bluff of the old valley previously mentioned in the text, extending between White Earth creek and Hofflund. The entry has been carried in thirty-five feet, showing a seam of lignite ten feet thick, lying between a light gray clay above and a darker clay below. The entry is so low that about four feet of the seam is covered with water while the creek is at its highest level. The mine is opened only to supply a local demand, and situated as it is, thirteen miles from the nearest railroad station, the output will be small for some time to come.

On the opposite side of the valley, Mr. Hanson has an opening located at the top of the bluff overlooking the Missouri. Here the seam, four or five feet thick, lies but a few feet below the drift covering the hill. From Hofflund to Nesson postoffice an accumulation of gravel and alluvium along the river terrace obscures all outcrops, except one in the bank at Mr. Wescott's farm. This opening lies at the base of the gravel terrace which rises 100 feet above it. The seam is small and but little lignite has been removed.

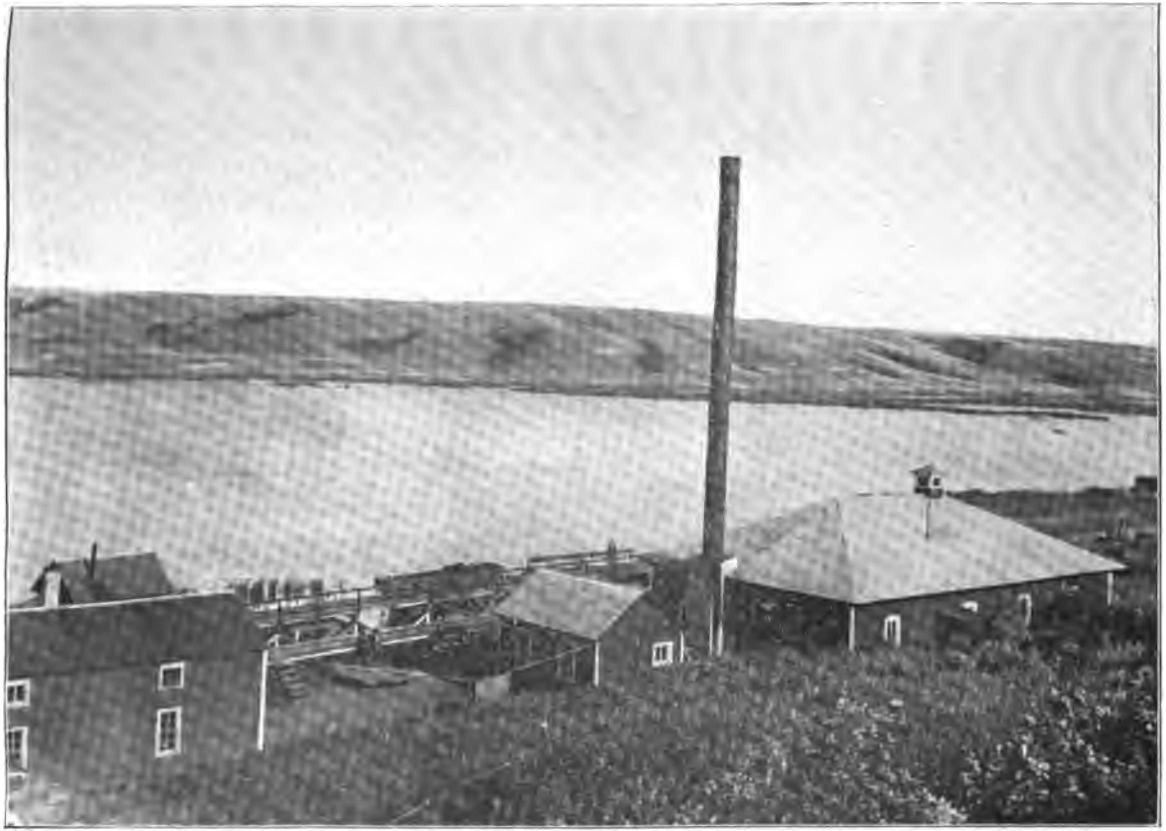
Three miles west of Nesson, in a bluff facing the Missouri, a seam of lignite eleven feet thick occurs at a height of 250 feet. Farmers get their fuel from this seam by scaling the bluff from the rear and rolling the blocks of lignite down the steep slope to the river level.

A dried sample from this seam shows the following analysis:

	PER CENT
Volatile matter	36.09
Fixed carbon	60.38
Ash	3.69
Total	100.00

Hofflund, Grennell, Chilcot.—In the steep face of the bluffs between Hofflund and Chilcot from one to eight seams of lignite are almost constantly in view. At Hofflund post office the black streaks alternating with the gray and yellow clay and the red burned clay that caps the bluffs, present a very pretty as well as striking illustration of the fact that conditions favorable for the formation of the lignite occurred only at intervals through a long series of years. At this point the seam remains nearly uniform in thickness for two miles, except where a three-foot seam thickens over a small area to six or seven feet. The seams that appear at Hofflund were seen again several miles below, but at most points the presence of a lower series of bluffs obstructs the view. From Grennell on down the river for three miles a bank of drift forty to sixty feet high hides the lower half of the bluffs of the Laramie strata, but where the bluffs again come into view seams of lignite two to four feet thick are seen. These continue in about the same elevation for several miles farther. At points fire has burned out the coal, as is shown by the red, brick-colored clays and the usually rough surface. Some of the lignite is so accessible that wagons can be loaded without driving off the road. The following is the analysis of a dried sample from a point three miles below Grennell:

	PER CENT
Volatile matter	43.04
Fixed carbon	51.60
Ash	5.36
Total	100.00



Power House of the Electric Mine at Kenmare.

Near this place and at nearly the same level, many petrified stumps having a diameter of from three to five feet appear in places.

Further on, for several miles on either side of the mouth of the White Earth, terraces of drift hide the lower fifty to sixty feet of the bluffs, but recent slides and the channels of spring streams open up lignite at numerous points. Just back of the Chilcot post office a seam of fair dimensions furnishes Mr. Hanna, the postmaster, with his winter fuel. But the drift on the prairie upland and in the terrace hides most of the lignite for a mile above and below Chilcot. Several seams again come into view at the group of buttes three miles west of Little Knife river.

Fort Berthold, Indian Reservation.—One and a half miles southeast of Mr. Black's ranch, at the mouth of the Little Knife river, there is a seam six to eight feet thick, from which considerable lignite has been taken. This opening is at the northwestern corner of the reservation and seventeen miles from the nearest Indian settlement at Shell creek. Between these two points the area within the big bend of the Missouri is so completely drift-covered that there is little chance of seeing outcrops of lignite, except along the banks of the river itself. Mr. Hoffman, who is in charge of the Shell creek mission school, reports lignite at points five miles west of the school, and also near the mouth of Shell creek.

Five miles east of the mission, at a point where the Missouri is undermining the bluffs very rapidly, several thin seams of lignite appear. Again, for nine mile farther on, drift and terraces obscure all outcrops within two or three miles of the river, though in the upper levels of the clays to the northeast of the road traces of lignite were seen.

Four miles northwest of the agency at Elbowoods, and again three miles north and east of it, several outcrops show a fair grade of lignite, the seam ranging from two to eight feet in thickness.

In one coulee at Elbowoods eight distinct seams, shown in figure 10, were counted in a bluff about 100 feet high. Three of these seams, aggregating eight or nine feet, may be mined as one.

The following analysis shows the constituents of the lignite. Sample taken three miles east of Elbowoods, from an opening that has furnished fuel for the agency:

	PER CENT
Volatile matter	37.29
Fixed carbon	57.95
Ash	4.76
Total	100.00

Sample from Mr. Edward Hall's place, two and one-half miles northeast of Elbowoods. The sample was taken from an opening where a spring issues from the lignite·

	PER CENT
Volatile matter	35.16
Fixed carbon	51.41
Ash	13.43
Total	100.00

Other openings were reported in the bluffs, three miles north of the agency, at Armstrong's.

The lignite seams appearing about Fort Stevenson and Coal Harbor are discussed by Dr. Wilder in his report on McLean county.

The following table gives the mines and banks in Ward county from which lignite is taken, in alphabetical order. By noting the value of machinery and equipment the amount of development in each case can readily be determined:

MINES AND BANKS IN WARD COUNTY.

Mines and Openings	Number of Men Employed Summer and Winter	Wages Paid Summer and Winter	Part of the Year Mine in Operation	Output of Mines Per Diem Summer and Winter	Value of Machinery Equipment	Thickness of the Seam	Approximate Elevation of Seam Above Sea Level	Time That Mine Has Been in Operation	Area Worked Out	Elevation of Seam Above Drainage Level
1—Anderson 155-92-13	....	....	....	Recently opened	....	6 to 7 feet	2,000 feet	6 months	Surface only	(Approximate)—8 feet
2—Beavert 161-91-16	....	....	Occasionally	....	....	....	1.750 to 1,800 ft.	Unknown	Surface	20-30 feet
3—Colton* 155-83-18	....	....	....	....	....	10 to 11 feet	1,630 feet	Several years	40 to 60 acres	....40 feet
4—Carroll Brothers 158-85-28	Summer, 3 Winter, 30	Summer, $1.75-$3	Continuously	5-50 tons per day	$2,500	3 to 5 feet	1,720 feet	Several years	1-6 of an acre	....35 feet
5—Dakota Lignite & Brick Co. 155-83-18	6-8 at time mine was visited	$2-$2.50	Coal not yet reached	....	$2,500	10 feet	1,630 feet	Just being opened	....	....40 feet
6—Diamond Kenmare	Fall and winter, 15-25	....	Continuously	Fall, winter, 100 tons per day	$4,000	5 feet	1,790 feet	Several years	Large; many acres	30-41 feet
7—Des Lacs* Des Lacs	....	....	....	....	$2,000 to $4,000	11 feet	1,590 feet	Several years	....	....
8—Des Lacs Valley Coal Co. 156-84-31	Summer, 6-7; winter, 25	Entry, $1; room, 70c	Continuously	Summer, 15 tons a day; winter, 70 tons a day	$1,000	10 feet	1,630 to 1,640 ft.	Several years	Several acres	....25 feet

MINES AND BANKS IN WARD COUNTY—Continued.

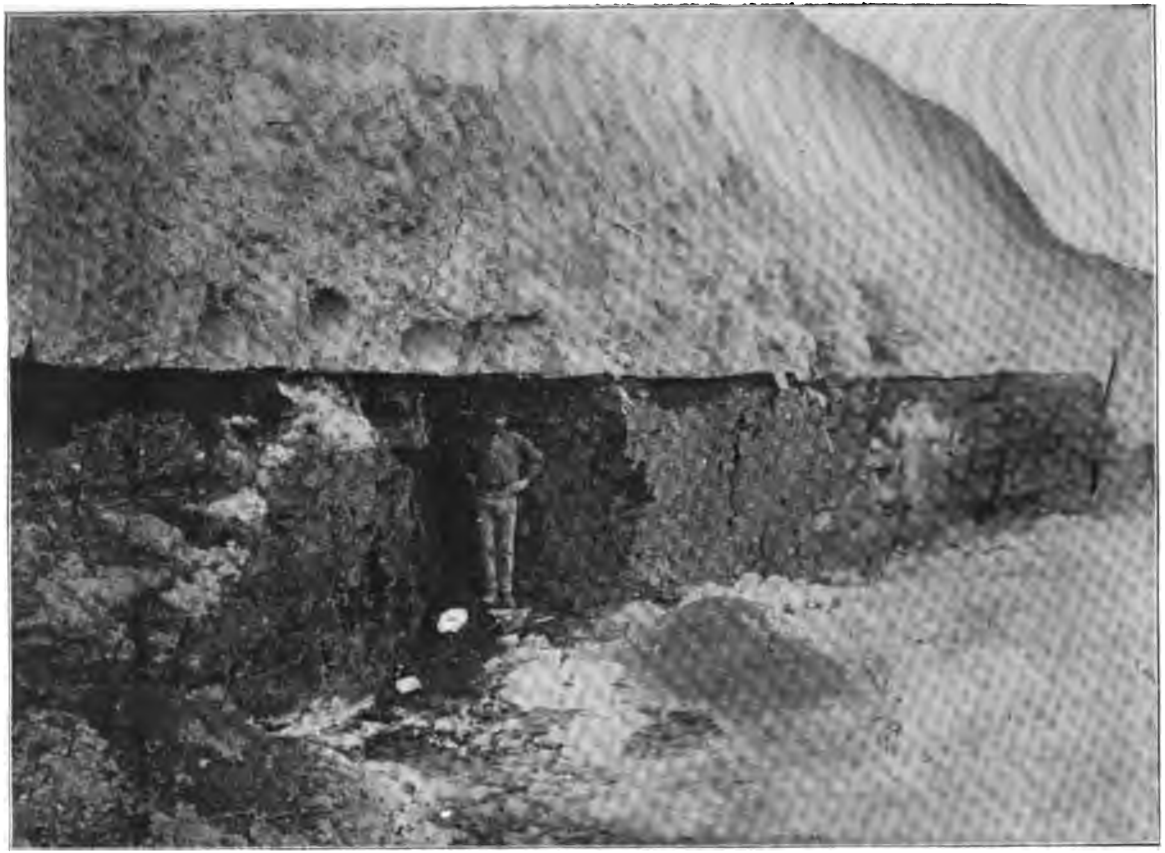
Mines and Openings	Number of Men Employed Summer and Winter	Wages Paid Summer and Winter, Entry and for Room	Part of the Year Mine in Operation	Output of Mines Per Diem Summer and Winter	Value of Machinery Equipment	Thickness of the Seam	Approximate Elevation of Seam Above Sea Level	Time That Mine Has Been in Operation	Area Worked Out	Elevation of Seam Above Drainage Level
9—Des Lacs Coal & Brick Co., five miles above Kenmare	Summer, 3-4; winter, 15-20	Entry, $1; room, 90c	Continuously	Winter, 40 to 50 tons a day	$2,000	5⅓ feet	1,790 feet	Recently opened	Unknown	....30 feet
10—DePue 152-81-27	2-5	$2	Recently opened for business	Winter, 10 to 20 tons	$5	11 feet	1,580 to 1,600 ft.	Coal removed for several years	Surface	....20 feet
11—Electric 160-89-12	Summer, 10-20; winter, 90-100	70c per ton	Continuously	Summer, 25 tons; winter, 300 to 500 tons	$20,000 to $30,000	4 to 7 feet	1,790 feet	Recently opened	¼ acre	....30 feet
12—Evans 161-88-30	Summer, 2-3; winter, 10-15	....	Continuously	(1,000 to 2,000 tons per year)	$100	4 to 8 feet	1,790 feet	Several years	Unknown (large)	....15 feet
13—Fleckteen 161-88-31	Summer, 1-3; winter, 5	....	Continuously	Winter, 10 tons	$50	4 feet	1,190 feet	1 year	Smaller	....15 feet
14—Gille-Miller, 162-93-20	1	Miner shares profit	Continuously	8 to 10 tons	$25	11 feet	1,800 feet	1 year	¼ acre	....25 feet
15—Honeywell 155-85-12	2	Mine leased by laborers	No output yet	....	$5	8 to 10 ft.	1,600 feet	....	Entry 100 ft.	....40 feet
16—Hanchette 152-81-29	2-5	$2	Recently opened for business	Winter, 10 to 20 tons	$5	11 feet	1,580 to 1,600 ft.	Coal removed for several years	Surface	....20 feet

17—Kenmare Hard Coal 160-88-32	Summer, 15-25; winter, 30-50	$2.50	Continuously	Winter, 250 tons	$3,500	4 to 5 feet	1,790 feet	1 year	½ acre	30 to 40 feet
18—Klondike* Burlington	....	....	....	....	....	10 to 11 ft.	1,600 feet	Several winters	Unknown (caved in)	15 to 25 feet
19—Leigh-Ericson 158-87-5	Summer, 3	Laborers own mine	Continuously	Unknown	$50	3 to 4 feet	1,770 feet	Part of the year	Entry, only 150 feet	40 feet
20—Mouse River Lignite Co. 155-84-12	Summer, 15 to 25; winter, 50 to 75	Entry, 80c; room, 50c	Continuously	Summer, 75 to 100 tons; winter, 200 tons	$20,000 to $25,000	10 feet	1,600 feet	4 years	Several acres	40 feet
21—Messinger 162-93-28	....	....	Winter	Total output a few tons (50)	None	4 to 7 feet	1,800 feet	1 year	Small	25 feet
22—Makee Bros. 164-93-31	1	....	Continuously	1 to 3 tons	$50	5 to 6 feet	1,800 feet	2 years	1 acre	12 feet
23—Norstrom-Rinos 156-85-32	Summer, 2 to 3; winter, 10 to 15	Room, 60c	Continuously	Summer, 5 to 10 tons; winter, 25 to 40 tons	$100	10 feet	1,600 feet	....	1 acre	10 feet
24—New Era 155-84-15	20 to 25	$2.75	Continuously	None yet	Plant yet incomplete	11 feet, 9 inches	1,590 feet	Just sinking shaft	....	....
25—Pleasant Valley 155-89-30	....	....	Intermittent	Just opened 50 tons total	....	5 to 7 feet	1,950 feet	....	....	3 feet bottom
26—Reishus 154-82-33	1 to 2	....	Continuously	Few tons	$5 to $10	2 to 3½ ft.	1,500 feet	1 year	Entry	8 feet
27—Renwle* 157-93-18	....	....	....	Total, few tons	None	3 to 4 feet	2,000 feet	....	Surface	30 feet
28—Syndicate* 155-83-30	....	....	One winter	250 tons	....	6 to 7 feet	1,600 feet	½ year	Entry 150 ft.	25 feet
29—Scribner 156-84-19	Summer, 5 to 6; winter, 10 to 20	Entry, 80c; room, 170c	Continuously	Summer, 8 to 15 tons; winter, 30 to 40 tons	$50	10 feet	1,600 feet	2 years	½ acre	25 feet

MINES AND BANKS IN WARD COUNTY—Continued.

Mines and Openings	Number of Men Employed Summer and Winter	Wages Paid Summer and Winter, Entry and for Room	Part of the Year Mine in Operation	Output of Mines Per Diem Summer and Winter	Value of Machinery Equipment	Thickness of the Seam	Approximate Elevation of Seam Above Sea Level	Time That Mine Has Been in Operation	Area Worked Out	Elevation of Seam Above Drainage Level
30—Swartz x 159-88-32	Summer, 3; winter, 10-20	Entry, $1; room, 75c	Continuously	....	$100	4 to 5 feet	1,790 feet	....	Entry several hundred feet	25 feet
31—Smith-Kenmare 167-88-7	Sept. 1 to March 1, 50	Entry, $1; room, 70c	Continuously	Aug. to June, 1902, 6,500 tons	$2,000	6 feet	1,790 feet	Several years	Several acres	5 feet
32—Smith-Jones 161-88-29	4	Entry, $1.25; room, $1	Continuously since opening	5 to 30 tons	$2,500	4½ feet	1,790 feet	One summer	Entry	30 feet
33—Turtle Gulch, 152-82-15; W. 2, 152-82, 11-15 2	Not opened when visited	....	....	....	....	11 to 14 feet	1,000 feet	....	....	3 feet
34—Sorenson* 162-92-32	....	....	....	....	....	3 to 7 feet	1,800 feet	....	Surface	8-15 feet
35—Hart Mine Kenmare	....	....	....	....	....	3 to 4 feet	1,790 feet	Recently opened	Entry, 100 ft.	40 feet

* Mines abandoned. x Silver Vein coal mine.



Part of an Eleven-Foot Seam Ten Miles Southwest of Velva; the Hanchett Mine.

LIGNITE DEPOSITS OF MORTON COUNTY

FRANK A. WILDER

Topographic conditions in this county greatly favor a study of the lignite. The Missouri and Cannon Ball rivers bound it on the east and south, while the Heart river crosses it near the center from east to west. Sections through a considerable thickness of Laramie clays, therefore, are abundant. The older drift which covers most of the country conceals the underlying formations but slightly. The county is crossed near its northern boundary by the Northern Pacific railroad, and a fair opportunity is offered for shipping the lignite in which the county abounds to portions of the state less favored in this respect.

The Mine of the Consolidated Coal Company at New Salem.—This is the largest mine in the county and an extensive producer of good coal. Although opened up only in the spring of 1901, its output for the year, from July 1, 1901, to July 1, 1902, was 10,000 tons. During the present winter the output will be double that of last year.

The mine is situated on a hillside, one mile from the town of New Salem. The entry runs into the hill, following the coal. A uniform double entry and room and pillar system of mining is being developed. The seam mined is six feet thick, including a two-inch clay seam, all of which is removed, the stiff clay above forming a substantial roof. No water has as yet been encountered, and if it develops as mining progresses, conditions for drain-

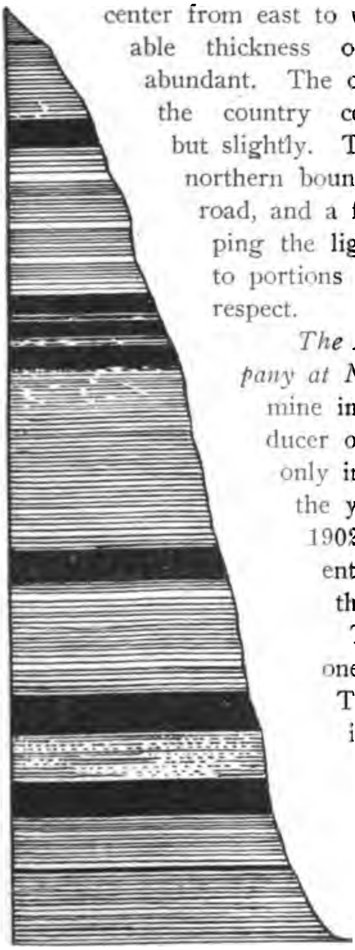


Fig. 10.—Section showing lignite seams at Elbowoods, on the Indian reservation.

age are favorable. The lignite shows a slight dip toward the southeast.

The quality of coal from this mine renders it popular for use in stoves, while the mine of the same company at Lehigh, in Stark county, supplies their patrons with steam coal.

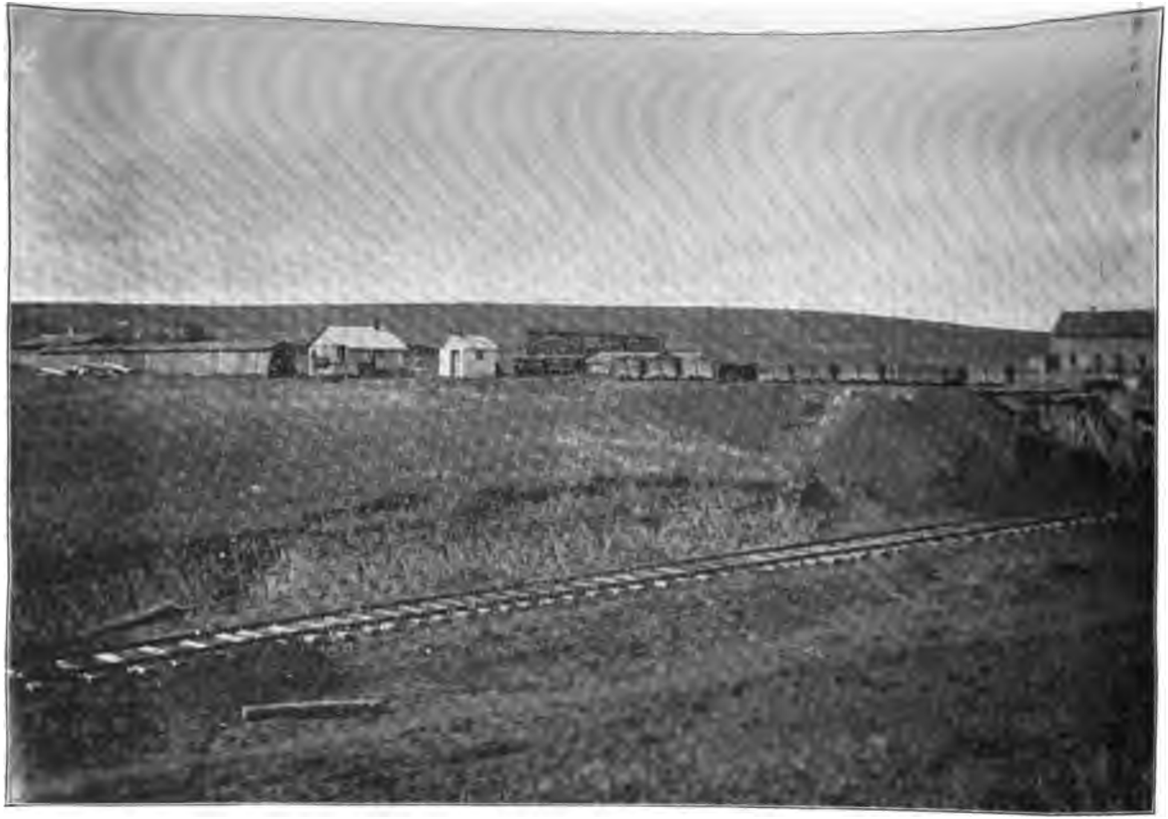
The men receive 60 cents a ton for pick work in rooms and $2.50 a yard for running entries. Practically all of the mining is done as piece work.

Analysis of the lignite from this seam shows:

	PER CENT
Volatile matter	41.66
Fixed carbon	53.86
Ash	4.48
Total	100.00
Moisture	27.48

Other Lignite Banks About New Salem.—Three miles east of Sims and about an equal distance south of New Salem, in Township 138, Range 85, Sections 4 and 5, considerable quantities of lignite are won by stripping. At the first bank visited only the upper part of a seam said to be seven feet thick was visible. A little farther on a second bank was found which showed six feet of good lignite. This seam is about eighty feet below the average upland level. In Township 139, Range 85, Section 32, just south of the banks mentioned above, a large bank of good lignite, five feet thick, is operated, the annual output amounting to 2,000 or 3,000 tons. The coal is won by removing from fifteen to twenty feet of overlying clay. In Sections 34 and 35 of the same township, a seam six feet thick, apparently the same as that exposed in the banks just described, is mined for local use. The seam at the New Salem mine appears to be somewhat higher than the lignite in any of these openings, but the observations made were not complete enough to decide whether it represents an independent seam.

In Township 138, Range 85, Section 8, a twelve-foot seam of lignite is reported by Mr. W. H. Mann. Six feet of lignite occur in Township 139, Range 85, Section 31, on the land owned by Baron E. Von Stoltefoot. Just east of Sedalia, on the Northern Pacific railroad, in Township 139, Range 84, Section 29, five feet of lignite is exposed, while in Section 4 of the same township the same seam, or at least lignite of the same thick-



Mine of the Consolidated Coal Company at New Salem.

ness and about the same level occurs. Other seams reported by Mr. W. H. Mann, of New Salem, as occurring about New Salem, are as follows:

LOCALITY	THICKNESS
Township 138, Range 85, Section 28	Not known
Township 139, Range 85, Sections 34 and 35	6 feet
Township 139, Range 87, Section 9 or 10	6 feet
Township 139, Range 87, Section 1	6 feet
Township 141, Range 86, Sections 3 and 11	5 feet
Township 141, Range 86, Sections 33 and 36	6 feet

Lignite in the Vicinity of Sims.—The country around Sims is strongly rolling, and although it is crossed by no large streams, exposures of lignite are common in the hills. Hailstorm creek, a tributary of Big Muddy creek, which in turn empties into the Heart river, flows through a hollow which the Northern Pacific railroad here follows. Along this creek are the larger mines. The section shown along the creek banks, both north and south of Sims, is as follows:

		FEET	INCHES
11.	Clay	40	..
10.	Lignite	2	..
9.	Clay	..	6
8.	Lignite	2	....
7.	Clay	40	..
6.	Sandstone, often cross bedded	3	6
5.	Clay	60	..
4.	Lignite, impure	4	..
3.	Clay	10	..
2.	Lignite	7	..
1.	Clay	12	..

No. 2 of the section, which is nearly on a level with the railroad, is the seam mined.

The Wadeson Mine.—Lignite has been mined by Mr. Wadeson for a number of years in the vicinity of Sims. The common method has been to drift into the hill till the haul to the surface became too long, and then to start afresh. A number of old entries excavated in mining after this manner may be seen a few feet above the railroad track. At present, however, a power plant is in operation and a more careful method is planned. The drift slopes down gradually till it strikes the coal, about twelve feet lower than the entry and at about creek level. The present entry is in 600 feet and shows that there is considerable irregularity in the position of the lignite, the seam often rising or falling two feet in a hundred. One-fourth of a mile farther south the lignite is seventeen feet higher than at the Wadeson mine. Six inches of coal are left to strengthen the roof. Some water follows the seam and about 4,000 gallons are pumped daily. One Harrison compressed air drill is in operation part of the time, but most of the mining is done with the pick, as piece work.

The output last year was 5,000 tons, and the average price at the mine $1.50. The mine is on leased land and a royalty of 7 cents a ton is paid.

Samples of coke reported by Mr. Wadeson as made by him from lignite were seen and appear to be of good quality.

An analysis of dried lignite from the Wadeson mine shows:

	PER CENT
Volatile matter	38.21
Fixed carbon	50.47
Ash	10.32
Total	100.00

The power house and tipple are shown in plate XXV.

The Burton Mine enters the same seam as the Wadeson, and except that it lacks a power plant, is of much the same nature and is operated in the same way. It is one-half mile south of Sims. An older opening on the opposite side of the coulee is not now operated on account of water. A stream which fills a two-inch pipe flows from the entry. The dip of the coal from the entry renders it somewhat difficult to arrange for the draining and development of these old workings.

The output of this mine last year was 8,000 tons. It is operated only during the fall and winter months. The quality of the coal is satisfactory, and it meets with a ready sale.

The second seam, No. 4 in the section given, has furnished some coal at various points about Sims, but never has been systematically mined.

The log of the deep boring at Sims, quoted by Darton,* shows a number of seams lower than those mentioned:

	THICKNESS IN FEET	DEPTH BELOW SURFACE
Lignite	8	10
Lignite	5	70
Lignite	5	136
Lignite	5	330
Lignite	6	710

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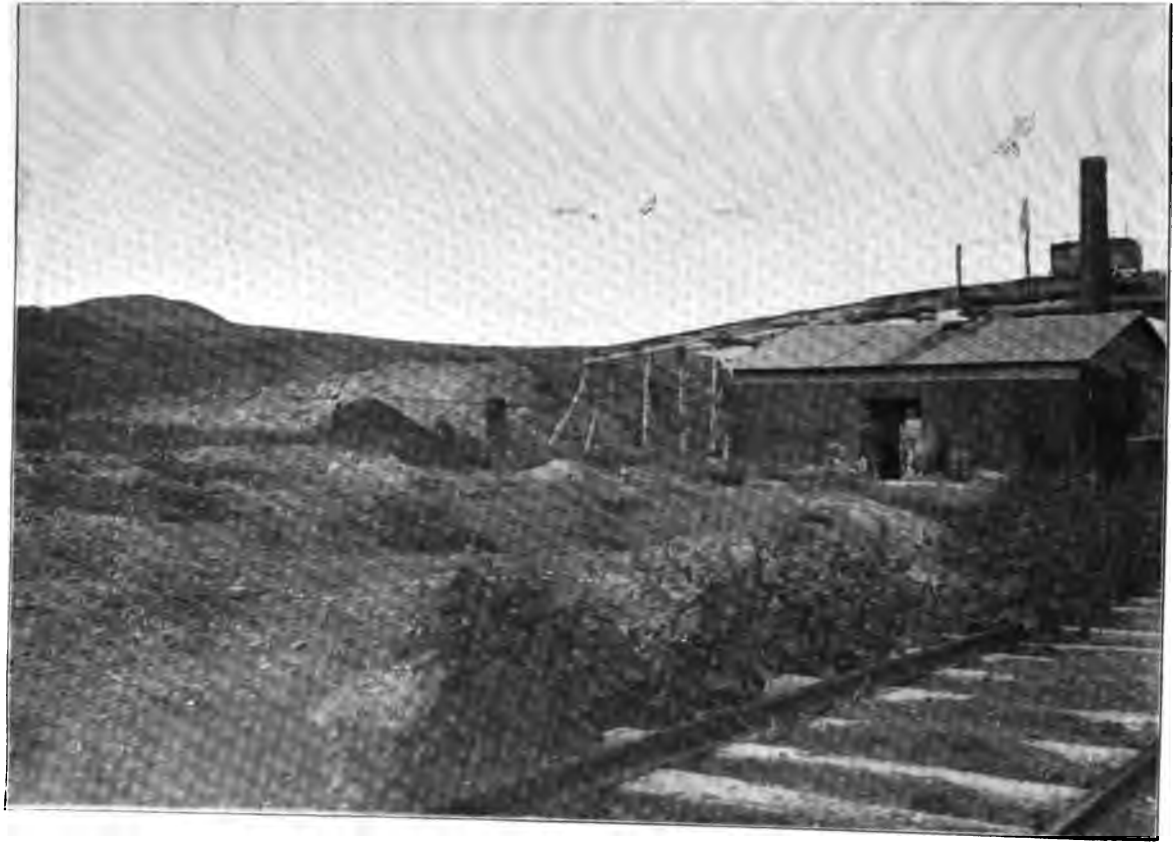
* Preliminary Report on the Artesian Waters of the Dakotas, p. 62.



The Wadeson Mine at Sims.

The first member of this series may represent the seam now mined, no data being given to determine this point. The remaining four seams, however, are in addition to those reported in the preceding section.

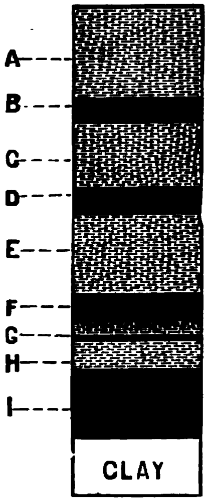


Fig. 11. The old Sims mine section,

The Old Sims Coal Company, which has been out of operation for some years, mined in the same seam now opened by the Wadeson mine, but on the opposite side of the creek, the seam there being twenty feet higher than at the Wadeson mine. Figure 11 shows the series at this point.

Coal in Other Parts of Morton County.—Coal in considerable quantities is reported about Heart Butte, and along the Heart river, throughout its entire course through the country. Large deposits are to be expected along the Cannon Ball and its tributaries in the county. Three miles north of Hebron, in Township 140, Range 90, Sections 6 and 16, a five-foot seam of good lignite is reported. South of this station lignite banks opened for local use are numerous.

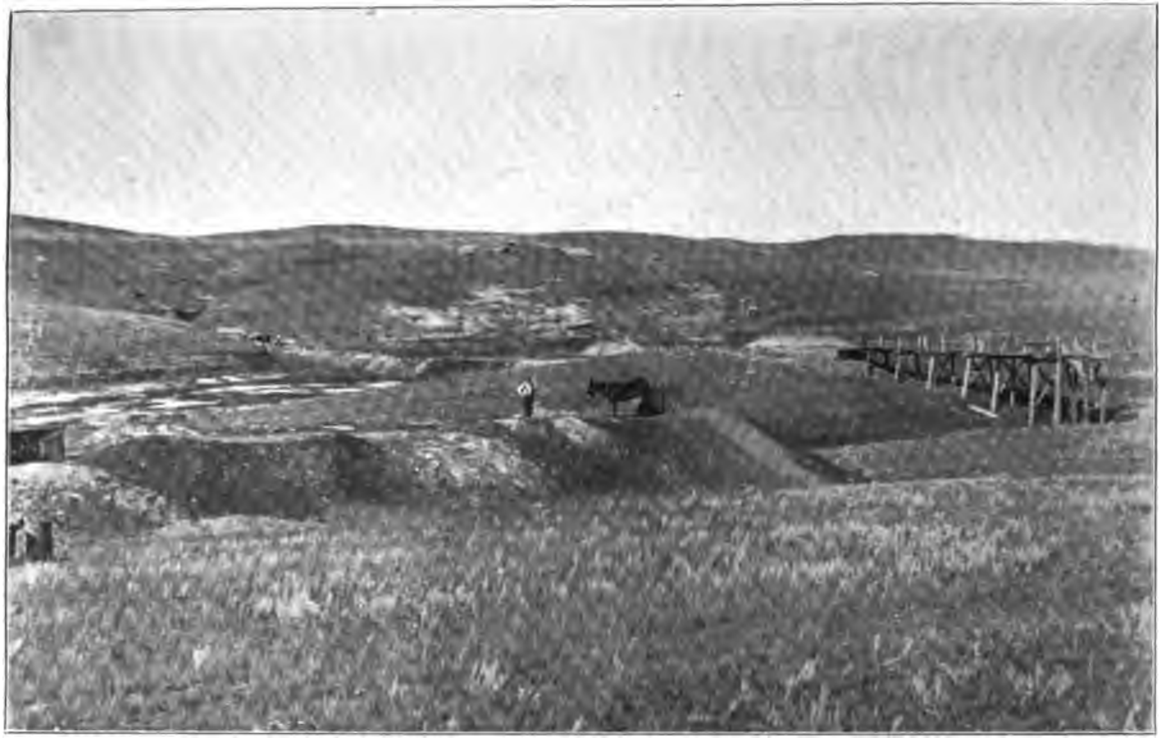
COAL DEPOSITS OF STARK COUNTY

Stark county is practically free from glacial drift, though glacial boulders are not uncommon in the eastern portion, and were observed at points where they could not be attributed to human agencies, as far west as Gladstone. The Northern Pacific railroad follows the Little Heart river through the western part of the county, bringing the natural exposures of coal early to the notice of investors and furnishing shipping facilities. As a result, the large mine at Lehigh was developed early in the history of the lignite industry. The topography of the county is well shown in plate XXXIV. High buttes rise here and there, usually capped with sandstone and not uncommonly containing deposits of high grade fire clays. The drainage systems are mature and the surface generally is moderately rolling. The Heart river rises at the western border and unites with the Green river near the center of the county. Along both streams, even near their sources, are extensive low terraces. They are fed perennially by springs which issue abundantly from the lignite seams; but on account of the evaporation in summer there are times when the water stands in the creek channels only in pools. It is a curious fact that in the fall, though no rain may have fallen, the streams gradually increase in volume till the flow is considerable.

The Mine of the Consolidated Coal Company at Lehigh.—A remarkably fine seam of coal directly on the railroad, varying in thickness from twelve to sixteen feet, has been developed by this company. It outcrops along the Little Heart river for about three miles, from three to six miles east of Dickinson, and on account of the proximity of the mine to this city the coal is known throughout certain parts of the state as "Dickinson coal." Between Dickinson and Lehigh the first good exposure of this seam occurs in Township 139, Range 95, Section 7. The river here is cutting into a bluff of Laramie clays on the right side, while on the left is a large alluvial flat underlain with recent gravels which lie directly above twelve feet of coal. The lignite has been mined here both in the bluff by drifting and along the edge of the flat by stripping. The amount of coal that can be won by removing twenty feet of sand and gravel here is very large, the flat at this point embracing at least twenty acres. It is possible that in spots old stream channels are cut through the coal, reducing the thickness materially and even removing it altogether. Still, making due allowance for this possibility, the locality affords an inviting opportunity for strip-pit mining on a large scale. Practically the same conditions prevail a little further east and north of the track, and the lignite is mined at a number of points by stripping.

Thirty feet above the thick seam at these points a three-foot seam is frequently exposed, and above this an equal distance a thinner and more variable seam. The whole series is shown in figure 12, where the black bands represent lignite.

Plate XXVI.



The Burton Mine at Sims.

At the Lehigh mine the thick seam is twenty feet higher than at the exposure a mile to the west. The characteristics of the seam are the same at both points, and, although there is a break in the exposure of half a mile, it may be safely affirmed that but one thick seam is exposed in this locality, and the difference in elevation is to be accounted for by the unevenness of the surface on which the coal was deposited. The seam contains no clay and only a foot or two at the top consists of the inferior "slack" coal. The dip of the seam is variable and slight, prevailing to the southeast.

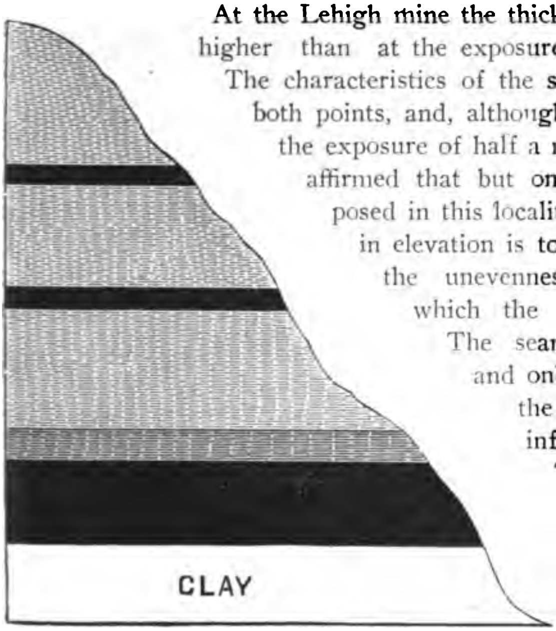


Fig. 12. Section at the Lehigh mine.

The "butt entry" system of mining is employed, which consists of running the rooms directly from the the mine entries. Entries are twelve feet high and from ten to twenty feet wide. The coal forms a great arch for a roof and practically no timber is used in the mine. Rooms are cut twenty feet wide, separated by six-foot pillars. When an area is about to be abandoned, the roof of the rooms is dressed down so that only two or three feet of coal are left. The great thickness of the seam facilitates mining, and the miners earn large wages at 40 cents a ton for room work and 60 cents for entries. The mine is practically free from water, the small amount entering it (October, 1902) being removed by a windmill. For ventilation air shafts with burning fire pots at the base are used. All hauling is done by horses, the large entries allowing the use of large animals, and a single horse brings to the surface cars containing three or four tons at one haul. A photograph of the tipple and side track at this mine is given in plate XXVII.

Analysis of the Lehigh coal after drying:

Bottom of layer:

	PER CENT
Volatile matter	42.63
Fixed carbon	49.22
Ash	8.14
Total	100.00

Two feet from bottom of layer:

	PER CENT
Volatile matter	43.57
Fixed carbon	46.50
Ash	9.93
Total	100.00

Three feet from bottom of layer:

	PER CENT
Volatile matter	39.99
Fixed carbon	51.60
Ash	8.41
Total	100.00

Four feet from bottom of layer:

	PER CENT
Volatile matter	40.70
Fixed carbon	48.24
Ash	10.89
Total	100.00

Five feet from bottom of layer:

	PER CENT
Volatile matter	44.32
Fixed carbon	48.53
Ash	7.15
Total	100.00

Six feet from bottom of layer:

	PER CENT
Volatile matter	41.50
Fixed carbon	51.80
Ash	6.61
Total	100.00

Seven and one-half feet from bottom of layer:

	PER CENT
Volatile matter	40.97
Fixed carbon	51.30
Ash	7.73
Total	100.00

Outcrops at mouth of tunnel:

	PER CENT
Volatile matter	37.06
Fixed carbon	54.06
Ash	8.88
Total	100.00

Lignite at Dickinson.—At two points on the outskirts of Dickinson considerable quantities of lignite are mined. The plant of the Dickinson Pressed Brick and Fire Clay Company is situated on a terrace of the Little Heart river about thirty feet above the water. This terrace gives the following section:

	FEET
Sandy clay	17
Impure lignite	½
Clay	3
Good lignite	5

Plate XXX illustrates this section. The clay is stripped from the lignite, and considerable quantities of it are made into brick, while the lignite is used in firing the kilns, even the thin, impure layer being profitably consumed. The five-foot seam is exposed at a number of points along the river.

The Lenneville mine, one-fourth of a mile east of Dickinson, shows an eight-foot seam which bows up at both ends, so that although the surface is level, the amount of stripping necessary in the center is twelve feet, while at the ends of it is only six feet, the total length of the exposure being only 120 feet. The bank is one-third of a mile from the river, and at least twenty-five feet higher than the seam mined at the Dickinson brick yard. The lignite ordinarily sells for $1.50 at the mine. A number of hundred tons are taken out annually.

Coal on Green River.—Throughout its entire course lignite outcrops abound on Green river. Near its mouth at Gladstone the coal, though excellent in quality, has not been found in seams more than five feet thick. At the Rust and A. B. Powers farms, in Township 140, Range 95, Sections 26 and 27, three miles from the mouth of Green river, a seam nearly five feet thick outcropping a few feet above the water of the river is mined by stripping for local use. The Laramie clays have in many places been removed by erosion, and gravel and alluvium have been deposited on the coal, and in the flat terraces so formed the amount of stripping necessary to secure the coal is often moderate. Two miles farther up the stream, in Township 140, Range 95, Section 22, west half, a three foot vein of good lignite is mined by the owner of the ranch on which it occurs.

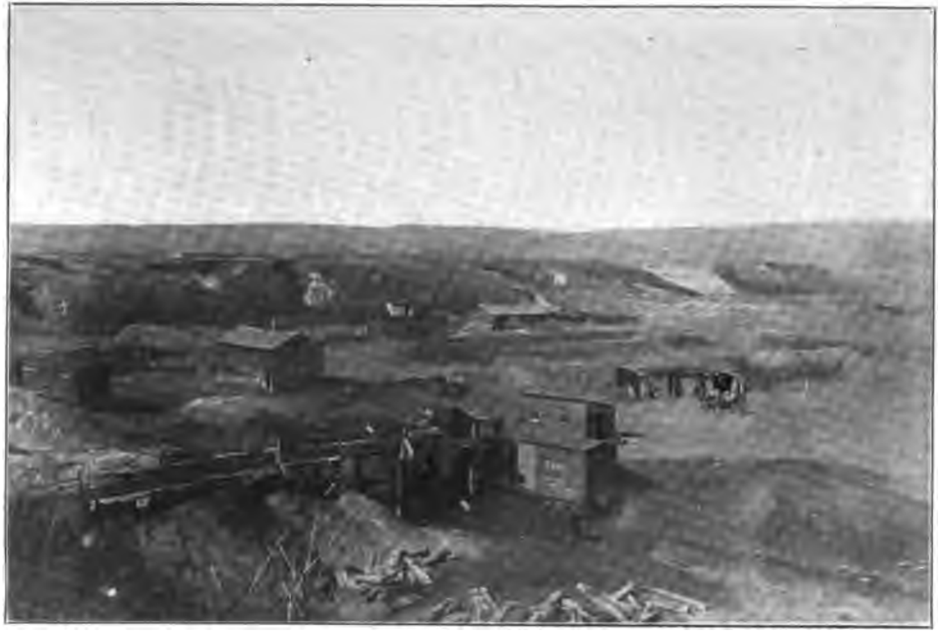
On the Green river, just north of Dickinson, at the Kupper ranch, a fifteen-foot seam of lignite is exposed. It rises from the water's edge and is covered with from ten to thirty feet of clay. Mining by stripping is carried on in winter, $600 worth being sold last winter, with the selling price only 50 cents a ton at the mine. The overlying clay is stripped off and dumped into the creek, which removes it during the spring floods. This seam is exposed at a number of points along the river for a distance of half a mile, and outcrops a mile and a half back from the river. It is shown in plate XXIX.

Between Dickinson and South Heart, on the Little Heart river, a four-foot seam about fifty feet above the river is mined at a number of points for local use. In Township 139, Range 97, Section 7, a seven-foot seam of soft lignite outcrops in a cut bank about thirty feet above the river. It is doubtful whether the quality of the coal improves back from the surface. Conditions favor the belief that the whole seam is soft.

Lignite About Belfield.—Coal is very abundant about this station, which is near the western boundary of the county, and the source of the Little Heart river. Along the Little Heart, between the station of South Heart and Belfield, are a number of excellent exposures.

The Bird-Stone coal bank, in Township 139, Range 98, Section 6, outcrops on the river, and so near the railroad that it may be seen plainly from the car window. The seam is sixteen feet thick, the upper half being soft and of doubtful fuel value in its present form, though possibly suitable for the manufacture of briquettes, when that industry shall be developed. Yellow streaks of iron oxide occur abundantly in the upper part and are readily mistaken for sulphur. They do not affect the fuel value of the coal. Analysis showing the average composition of the upper eight feet is as follows, dried before analyzing.

	PER CENT
Volatile matter	34.78
Fixed carbon	43.79
Ash	21.43
Total	100.00



The Mine of Consolidated Coal Company at Lehigh.

UNIV. OF MICH.

The lower eight feet of the seam appears to be of excellent quality. The dried coal gives an analysis:

	PER CENT
Volatile matter	35.71
Fixed carbon	56.61
Ash	7.68
Total	100.00

The bottom of the seam as now exposed is three feet above the river water level. Though the seam has been burned out at points, the body of coal in the vicinity of the outcrop is considerable. In Township 139, Range 98, Section 8, this same seam is exposed, and shows about the same characteristics, though it is somewhat thinner, the total thickness being about twelve feet. The bottom of the seam is here six feet above the river level. This outcrop is two-thirds of a mile south of the railroad track.

On the south side of the Little Heart, between South Heart and Belfield, back from the river and about forty feet above it, a six-foot seam of excellent coal outcrops. It may be seen best in Township 139, Range 98, Section 16, a school section. Here a coal bank has been opened from which several hundred tons are taken each winter. The stripping required at present amounts to but four feet, and coal can be won from a considerable area with no great effort. The twelve-foot seam may be looked for thirty feet below this one, though its thickness at this point cannot be predicted.

Coal North of Belfield.—Coal Mine creek, a tributary of the Little Heart river, which unites with it one mile east of Belfield, reveals great quantities of lignite along its course for five miles. In Township 140, Range 99, Section 34, a seam showing six feet of good coal was examined. A mile further up the creek, on Johnson's claim, a seam was made up as follows:

	FEET	INCHES
Soft lignite	2	..
Hard lignite	3	..
Clay	..	6
Hard lignite	1	..

In Township 140, Range 98, Section 28, six feet of lignite are exposed the lower three feet excellent in quality. In Township 140, Range 98, Section 27, seven feet of coal were seen, the lower four feet excellent. After an interruption by two inches of clay, the lignite continued and its total thickness was not known. These two exposures doubtless represent the same seam.

Other openings have been made along Coal Mine creek from which lignite is being taken, and the output from the banks along this stream will amount to several hundred tons this winter. At every opening springs appear, and many strong springs at points not developed indicate the presence of lignite.

One mile northwest of Belfield, in Township 140, Range 99, Section 30, sixty feet above the railroad track and at an elevation considerably greater than that of the seam just described on Coal Mine creek, five feet of a seam said to be nine feet thick was seen. The lignite appeared to be of excellent quality.

Lignite South of Belfield.—Three miles south of Belfield, on Norwegian creek, a tributary of the Little Heart river, which flows nearly east-west, and empties into the parent stream eight miles southeast of Belfield, there are a number of seams which are well exposed and locally developed.

The Engelhartson bank, in Township 139, Range 99, Section 20, shows four feet of good and two feet of inferior lignite. The bottom of the exposure is six feet above water level. The amount of stripping required at present is eleven feet, and a large area can be mined at no greater disadvantage. Lignite, probably the same seam that is opened one-fourth of a mile farther down the creek, was found in the barnyard, but heavy springs prevented the opening of a bank advantageously. The structure of the seam where exposed is as follows:

	FEET	INCHES
Soft lignite	..	8
Good lignite	2	6
Clay	..	6
Good lignite	1	6

The Anderson bank, on the same creek, in Township 139, Range 99, Section 19, north one-half, shows twelve feet of lignite, the lower six or eight feet good, the upper part of the seam being soft. As now exposed, from eight to ten feet of stripping is required to secure the lignite. The position with reference to water level of the stream is the same as that at the Englehartson bank, and the distance between them being only two miles, the two exposures probably represent the same seam. At the Anderson bank two thin streaks of clay occur in the lignite.

Other localities in this vicinity where lignite was reported by responsible persons, but which were not personally visited by a member of the Survey staff, are as folows:

The Anderson homestead, Township 139, Range 100, Section 24, sixteen feet of good coal reported to have been found in a well twenty-two feet below the surface.

On Paddy creek, a tributary of the Little Missouri, four miles north of Sully spring, lignite in eight and ten-foot seams.

On Government creek, a tributary of the Little Missouri, excellent lignite seams.

One mile west of Belfield, on the south side of the Northern Pacific track, a seam of some importance is slightly exposed, its total thickness being undetermined.

LIGNITE DEPOSITS OF HETTINGER COUNTY

A limited area only in Hettinger county has been studied, the greater part of the large area included within its limits being necessarily reserved for the field work of the coming summer. From New England as a center work was carried on up and down the north fork of the Cannon Ball for ten miles in each direction, south along Coal Bank creek, a tributary of the stream just mentioned, and just across the line in Billings county, in the Rainy buttes. The country between Dickinson and New England was twice traversed by different routes and observations with reference to lignite were made. The region is marked by a few high buttes, by one or two elevated plateaus of the same elevation as the low buttes which are plainly remnants of these and similar plateaus, and by extensive nearly level stretches in the valleys of the present streams.

The Rainy Buttes are large, flat topped buttes of the Sentinel butte type already described, and the stratigraphic series that they dislose is nearly identical with that of the other high buttes in Billings county. East Rainy Butte with its outliers occupies nearly two-thirds of a township, while the top includes an area one-third as great. The upper half is steep, the last fifty feet nearly vertical, the total height above the surrounding country amounting to 400 feet, its elevation above the Cannon Ball river reaching 460 feet.

Section of East Rainy Butte:

		FEET	INCHES
10.	Sandstone, gray, silicious, micaceous, often thin bedded, but in places very massive, locally coarse, with pebbles one-third inch in diameter	50	..
9.	Fire clay, white	25	..
8.	Sand, locally hardened, white	20	..
7.	Concealed	180	..
6.	Sand	10	..
5.	Lignite, good, with strong springs, exposed	6	..
4.	Clay	50	..
3.	Lignite	..	6
2.	Clay	10	..
1.	Covered	40	..

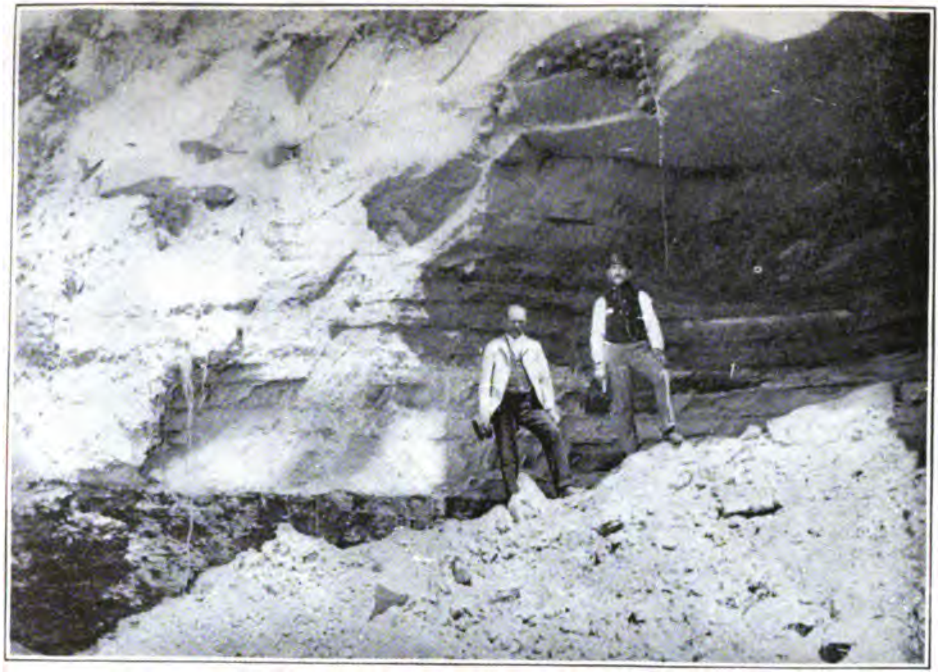
Lignite About New England.—The Laramie as exposed on the Cannon Ball at this postoffice consists of sand and sandstone, but two miles north of the river lignites and clays are found. The bank from which most of the coal for New England is obtained is that of Jacob Riess, in Township 136, Range 97, Section 22. Here a seven-foot seam of good coal is laid bare by stripping off four feet of clay. Large springs issue from the lignite. The seam is exposed along the edge of the hill where the bank is located for 300 feet. An analysis of dried lignite from this bank gives:

	PER CENT
Volatile matter	38.39
Fixed carbon	53.03
Ash	8.58
Total	100.00

Lignite from this bank sells for 50 cents a ton at this mine.

On John Ermintrout's ranch, six miles northwest of New England, lignite is mined by stripping. His bank shows:

	FEET
Lignite, poor	1
Lignite, good	1
Clay	1
Lignite, good	1
Clay	1
Lignite	Thickness unknown



Lignite Near Lehigh.

UNIV. OF MICH.

Along the Cannon Ball,, west of New England, are some excellent lignite exposures. Five and one-half miles west of this postoffice the following section is beautifully exposed in a cut bank:

	FEET
Alluvium	4
Sand	5
Clay	2
Lignite, good	4
Clay	4
Lignite, good	5
Clay	5
Water level.	

This exposure is continuous for 300 feet. A little lignite has been taken from this point by neighboring ranchmen.

Three miles farther west, under similar conditions, this series is practically repeated, and the persistence of the seams to this point may be assumed.

On Coal Bank creek, which rises eight miles south of New England, and flows northeast into the north branch of the Cannon Ball, lignite outcrops at a number of points and large springs and areas covered with scoria, both certain signs of the presence of lignite, occur. One four-foot seam of good lignite may be found four miles from the mouth of the creek, twenty feet above water level. Little prospecting has been done along this creek, or along the river farther east, and there is strong probability that an abundance of lignite will some day be brought to light.

Along the south fork of Cannon Ball river lignite is said to abound. Some excellent seams are reported on Grand river, just over the line in South Dakota.

LIGNITE DEPOSITS OF EMMONS COUNTY

Emmons county lies within the drift-covered area, and natural exposures that would reveal lignite seams are not common, except along the Missouri river, which forms its western boundary.

Near Livona, which is on the river, twelve miles south of Bismarck, some mining has been done. In Township 135, Range 75, the C. H. Edick mine has developed a seam two and one-half feet thick The outcrops occurred near the bottom of a coulee, and the lignite is won by drifting. At the mine the coal sells for $2.75 a ton, a price which shows the peculiar advantage in location. Southwest of Williamsport, in Township 135, Range 78, the Jesse E. Brindle mine at one time took coal from a two-foot vein.

Very little prospecting has been done of a sort that would reveal what lies below the thick covering of glacial drift. The county lies near the eastern border of the lignite area, but may be expected to contain considerable quantities of coal.

LIGNITE IN THE TURTLE MOUNTAINS

This plateau forms an eastern outlier of the Laramie series of North Dakota, and the strata beneath the glacial drift for 400 feet are like those of Ward county, namely, clays and lignite. The lignite outcrops at a number of points, for postglacial erosion has been vigorous and many ravines are cut deep into the clays. The best known of the natural exposures are north of Dunseith, while many others back in the hills are said to have been reported to Captain Brenner of Belcourt by the Indians on the reservation. Outcrops should be looked for also in the vicinity of Bottineau.

In 1886 a three-foot seam, which outcropped on a hillside two miles north of Dunseith, was mined by drifting, and it was found that the seam dipped toward the north at an angle of twenty or thirty degrees. Subsequently a vertical shaft seventy-five feet deep was sunk further back on the hillside, which encountered at that depth a seam said to be twelve feet thick, lying fifteen feet above the lowest point of the sloping seam. There is little doubt that the latter owes its slope to an extensive slip, and that the seam is really horizontal and will be found above the lowest point in the part that was subject to the slip; but it cannot be possibly affirmed that the seam reported as found at the base of the shaft is the same one. If the thickness is reported correctly, and the two occurrences represent the same seam, the increase in thickness is very rapid.

At present residents of Dunseith are opening up these workings, and the prospects for a successful mine are good. If the initial showing is satisfactory, considerable work will be done this winter. Lignite will command a good price, for wood in Turtle mountains is becoming scarce, and freight rates to this section from the Ward county mines are considerable.

SUMMARY OF MINING METHODS

As the brief descriptions given in the preceding pages show, practically all the lignite of North Dakota is mined by three well known systems: The strip-pit; drifting in on the seam, and shafts, vertical or sloping. The system that is in use at a given locality depends on two factors: The stage of development that the seam has reached, and the nature of the seam. The strip-pit system is the simplest, but a coal bank begun in this way generally passes with time into a drift mine. Later it may be found desirable to abandon the drift and sink a shaft. Local conditions, however, may interfere with this natural development, arresting it before the second and third stages are reached. Where capital is sufficient and other conditions are favorable, the preliminary stages are omitted and a shaft is sunk at once.

The Strip-pit System.—If statistics in regard to all of the local mines worked on this system in the lignite area were available, it would probably appear that at least half of the the total output of the state is mined in this way. The only expense in the form of equipment needed is a scraper and pick, and operations are usually carried on only during the winter when other work is not pressing. The wide distribution of the lignite, much of it near the surface, has made possible a local mine within ten miles of nearly every settler in the western half of the state. Often the lignite outcrops on his own farm and at times at his very door. A suitable natural exposure is chosen for operation, one where the overlying clay is not thick, where there seems to be a good body of coal of fair quality, and where there is an opportunity to dump the material removed from the coal at a low level. A hillside or a stream bank where the outcrop most naturally occurs offers these very conditions, and in these places most of the strip-pit or "scalp" mines are found.

The amount of stripping that can be economically undertaken depends on thickness and quality of the underlying coal, but ten feet may be regarded as a maximum where the coal is but six feet thick. In many localities where mining is carried on in winter the clay removed from the coal is dumped directly into the creek bed and carried away during the high water of spring. Where fair wages are paid for labor and teams and the haul is short, the cost of stripping is about 10 cents a cubic yard. An acre of land bearing a seven-foot lignite seam yields, by the strip-pit system, about 8,000 tons. As the distance from the creek bed or into the hill increases, the overburden grows, till this system is no longer profitable and it gives place to drifting.

Drift Mines.—The larger mines near the Mouse river, in Ward county and along the Northern Pacific railroad, are of this sort. Entries are run in on the coal, or beginning a short distance above it, slope down at an angle of ten or fifteen degrees till the coal is encountered, when the seam is followed. In all cases the room and pillar system is used underground. No lignite seam so thin as to make long wall mining advisable has yet been developed, except by the strip-pit system. Both single and double entry mines are to be found in the mining area, mines working double entry being more common. The lowest point in the mine is chosen for a "sump," and from this the water, which is generally present in some measure, is pumped. either vertically to the surface, or out at the entry.

Vertical or Inclined Shafts.—In mines where the equipment is expensive it is generally advantageous to sink a shaft to the lignite, though some seams, on acount of overlying quicksand, present difficulties to this method of mining. It is possible to bring the coal from all points of the compass to the foot of the shaft, and the underground haul, an item of considerable expense, is greatly reduced as compared with the drift mine, where a semicircle is the widest range for hauling. Where the depth of the mine is not great, as at the Washburn mine, a sloping entry may be recommended, since it obviates the necessity of elevators for the men and gives easy access to the mine. Where the distance to the coal is considerable, the vertical shaft, being shorter, is more suitable. The New Era mine, near Minot, will have a vertical shaft more than 300 feet deep when it reaches the lower or ten-foot seam. All underground work in these large lignite mines follows the room and pillar method. Instead of the ordinary double entry, the "butt entry" system is employed, in which the rooms are run directly from the main entries. As to size of rooms and pillars, there is a little variation in the lignite area from the practice common in the bituminous coal regions. A map of the Washburn mine is given in plate XXXI, showing the position of the shaft and entries, and the arrangement of surface works.

Mining Machines in Lignite Coal.—Mining machinery of standard types is in successful operation in three of the lignite mines, and most of the larger mines now under construction will be equipped with electric machinery. The freedom of the lignite seams from nodules of pyrites and other foreign substances renders them an especially fit field for the operation of undercutting machinery. At present the price paid for labor is higher than in older mining centers and it is more uncertain, the high price paid during harvesting resulting in the practical desertion of many of the mines. For all of these reasons the introduction of labor saving mining machinery is especially desirable. Undercutting machines and electric drills operate in lignite with about the same speed that is obtained in common practice in bituminous fields. Where the lignite is very solid, "shooting from the solid" is effective, and the advantages offered by the undercut mining machines are reduced. When the coal is badly checked, however, the powder does not take hold, but blows out along the cracks bringing down very little coal. Here the undercut machines may be introduced to great profit. The lignite in a given mine may differ in different parts sufficiently to render the undercut machine desirable at one point while its use offers no economy at another.

Peculiarities of Roof and Floor.—With but one or two exceptions, it is necessary to leave from six inches to a foot of the lignite seam to form a roof, for the overlying clay is rarely tough enough to stand without the aid of this support. At none of the mines now in operation does sandstone occur above the coal in a way avaliable for roof, and at no point visited was a hard rock layer so advantageously placed, though one instance of this sort is said to exist in the vicinity of Glen Ullin, where a sandstone layer a foot thick will make a substantial roof over an eight-foot seam. From the given thickness of a seam, therefore, a deduction of six inches or more must be made in nearly every case, without regard to the purity of the coal, in computing its available thickness.

The floor is always a stiff, so-called "fire" clay, though the application of this term to the under clay seldom has any reference to its ability to withstand high temperatures. The peculiar tendency of Laramie clays to slip or move slowly under pressure sometimes manifests itself in an undesirable way in the floor of the lignite mine. In one or two instances this "pinching up" of the entries presents a serious difficulty, and, if roof or floor are untrimmed, an entry may be nearly closed in three years by this process. Most of the mines, however, have experiencd no trouble from this point.

Timbering in Lignite Mines.—In only one or two mines are the entries timbered in accordance with the standards recognized in the bituminous region of the central states. This raises the question as to the necessity of timbering.

Where the seams are not thick enough to make it practicable to leave part of the lignite for a roof, timbering is generally necessary in the entries, though in at least one instance a stiff upper clay makes a roof, to all appearances satisfactory. When possible, it is considered economical to leave coal for a roof and do very little timbering. The roof so formed generally appears firm and free from danger, though the mining interests of the state are now sufficiently developed to justify the employment for a few months each year of a mining expert, who shall determine the mine conditions with respect to the safety of the operators, and report to the state authorities.

Mine Water.—A certain amount of water may be expected in developing a lignite mine. A few of the mines that have been in operation for some time are wholly free from water, but generally a moderate amount of pumping is required, and in no case is it excessive. The presence of springs in connection with outcrops of lignite has been frequently noted in the foregoing descriptions. Lying between impervious clays, the lignite forms a natural watercourse. In a region where water is scarce the presence of these springs is very desirable, and there are few localities where a mine might be established where the water that would be removed from it would not during part of the year pay for the cost of removing it, for purposes of irrigation. It is generally potable and free from salts that would render it unsuitable for most purposes.

Mine Ventilation.—Dangerous gases are very rare in the lignite mines of the state, and but one accident has occurred that was attributable to them. This was an explosion of fire damp in one of the Ward county mines. The fact that such accidents may occur, however, renders important the installation of proper ventilating appliances. In but two or three mines are fans employed to secure a proper circulation of air within the mine. Ordinarily an air shaft with a fire pot suspended at its base is deemed sufficient. The inadequacy of this method in some of the larger mines, where the entries are long and the amount of powder burned is large, is manifest in the heavy air and a smoke lingering long after a discharge.

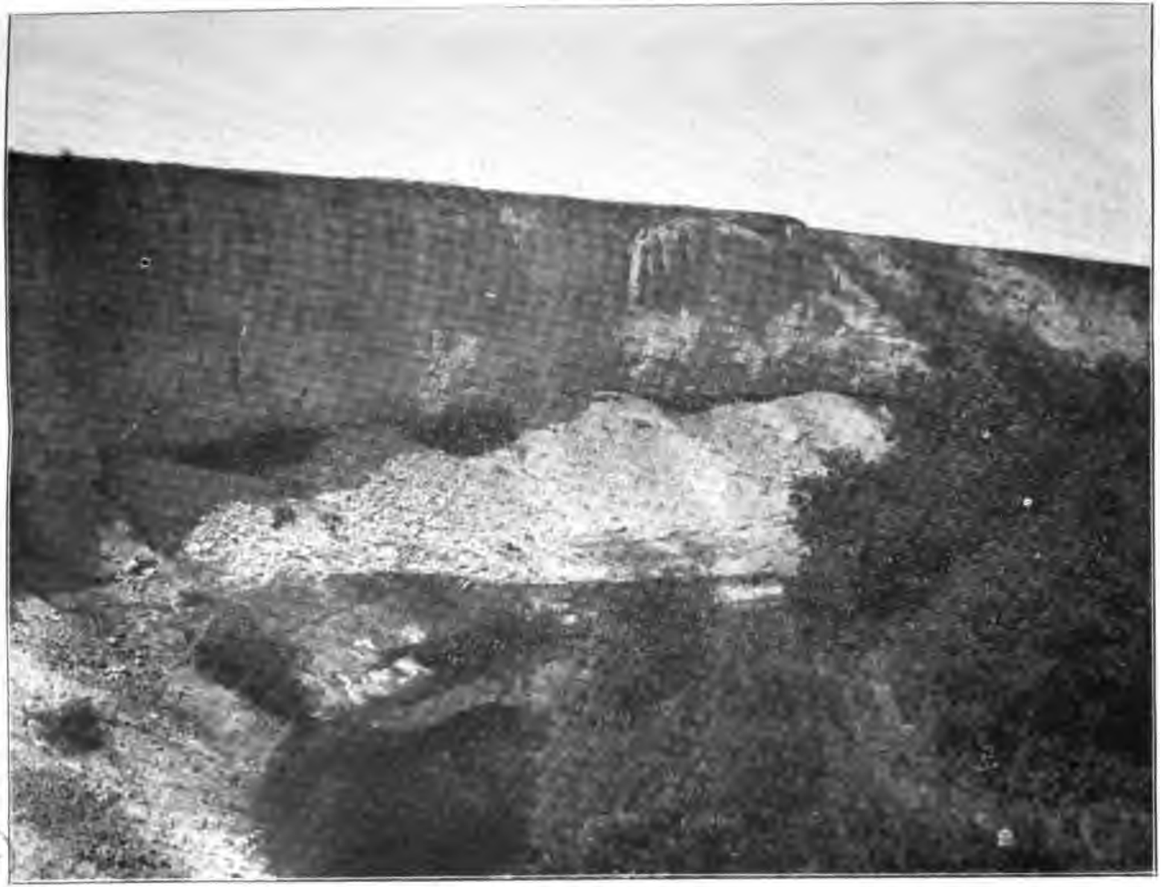
Blasting in Lignite.—Powder is generally used for shooting in mines, though dynamite proves effective in the open pit. Under favorable conditions, as in the mine at Lehigh, a six-foot hole is drilled, and in this three pounds of FF powder brings down on the average three tons of lignite.

Lignite on the Missouri River west of Washburn.

THE FUEL VALUE OF THE LIGNITES OF NORTH DAKOTA

The fuel value of a given lignite will vary considerably with conditions under which and the purpose for which it is used. In one connection it may be esteemed highly and in another not at all. Out of this fact grows the diversity of opinion in regard to a number of well known lignites of the state. A lignite whose value as a steam coal is very high may not prove suitable for certain kinds of stoves. An actual case will serve well for illustration. In two localities lignite from seams that are high in ash, due to admixture of clay are thought well of for heating purposes, because the clay enables them to stand up well and prevents slacking. Judged by ordinary standards these lignites are very inferior. These recognized standards are: The amount of fixed carbon and the percentage of ash that the lignite contains; the result given by the calorimeter, and the amount of water which a given amount of lignite will evaporate. Of the three tests the last is the most satisfactory. The lignites have been tested in accordance with these, as well as in a variety of practical ways, and a brief statement of results is proposed in this chapter.

Chemical Properties of the Lignites.—Coal in all of its forms, as well as peat, is derived from vegetable tissue which is composed of carbon, hydrogen and oxygen. When not exposed to the atmosphere, and hence free from ordinary decay, these three chemical elements tend to rearrange themselves, part of the carbon uniting with part of the oxygen to form carbon dioxide (CO_2), another part uniting with part of the hydrogen to form the inflammable gas (CH_4), while other parts of the oxygen and hydrogen combine to form water The proportion of the carbon entering into these combinations is lower than that of the other elements, and as these gases escape the percentage of carbon remaining uncombined grows higher. Conditions, there-



A Fifteen-Foot Lignite Seam on Green River, Eight Miles North of Dickinson.

fore, which favor the formation and escape of these gases, favor the formation of a coal which is high in uncombined or "fixed" carbon.

Conditions which favor the formation and escape of the gases formed by the decay of wood out of ordinary contact with the atmosphere are: Pressure, heat, folding and erosion of the containing strata, which allows the escape of the gases, and time, which is necessary for the chemical transformation, ordinarily slow.

In accordance with these conditions, coal in the older formations and in regions of tilted strata often contains a very high percentage of fixed carbon and is classed as anthracite. Where the formation is young but the region one of tilted strata, and of crushing, bituminous coals are common; whereas coal which, in the geological sense of the term, is recent, and forms part of a horizontal series that has not been subjected to great pressure or folding, is nearly certain to have a comparatively low percentage of fixed carbon. These are practically the conditions under which the lignites are found.

Fixed Carbon.—The average amount of fixed carbon in twenty-six samples of North Dakota lignite analyzed in 1900, when thoroughly dried, was 52 per cent. Sixty samples analyzed this year, after thoroughly drying, gave 51.21 per cent of fixed carbon. Compilations given in a former report of this Survey* show, for forty-one samples of West Virginia bituminous coal, 67.16 per cent of fixed carbon; for twenty-two samples of the better grades of semibituminous dry coals of Maryland, 75.99 per cent, and for twenty-six samples of dry bituminous coal from Pennsylvania, 67.97 per cent. Judged by the fixed carbon alone the heating power of one ton of North Dakota lignite is worth 76 per cent of a ton of West Virginia bituminous; 65.9 per cent of Maryland semibituminous, and 74.4 per cent of Pennsylvania bituminous. These figures show that the North Dakota lignites rank far above the coals that are the average representatives of this class.

Comparing the lignites of North Dakota with the product of the west interior coal fields, which includes Iowa, Missouri and Kansas, with respect to fixed carbon, the lignite appears to be its equal. Taking the recent United States report* and computing them on a dry basis, the average amount of fixed carbon for twelve samples is about 50 per cent. These coals, however, give a slightly higher evaporative test than do the lignites. By both standards, however, the lignite appears to be practically equal, when properly burned, for steam purposes, to the coals of Iowa, Missouri and Kansas.

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* First Biennial Report, E. J. Babcock, pp. 81, 82, 83.

Volatile Matter.—The average amount of volatile matter computed from sixty analyses of different lignite coals is 35.63 per cent. When the fixed carbon alone is considered as determining the fuel value of a coal, the worth of the volatile matter is overlooked. Under proper conditions these gases may be made to develop a great deal of heat, and no appliances which aim at an economical combustion of lignite can afford to disregard them.

The Percentage of Ash in the sixty samples analyzed this year is generally low, the average amounting to 8.5 per cent. Compared with the coals of Iowa, Missouri and Kansas regions, the lignites are notably purer. An average of twelve samples described in the report on this area already quoted gives 10.1 per cent of ash. In the ash from some North Dakota coals there is a tendency to form clinkers, due to the presence of clay, but generally the lignite burns like wood, leaving a gray, powdery residue.

Sulphur.—The percentage of sulphur in the lignites is usually low, much lower than in most bituminous coals. The following samples are fairly representative:

MINE	SULPHUR
Lehigh	0.88 per cent
Washburn	0.91 "
Forty-Foot Vein, Billings county	1.10 "
Electric mine, Kenmare	0.68 "
Davis mine (Mouse River Lignite Co.)	0.35 "

The sulphur in these analyses was determined in dry coal, which brings the percentage one-fourth higher than for lignite fresh from the mine.

A yellow powder, composed of calcium sulphate and iron oxide, occurs often in the upper part of lignite seams, and in color and texture resembles sulphur.

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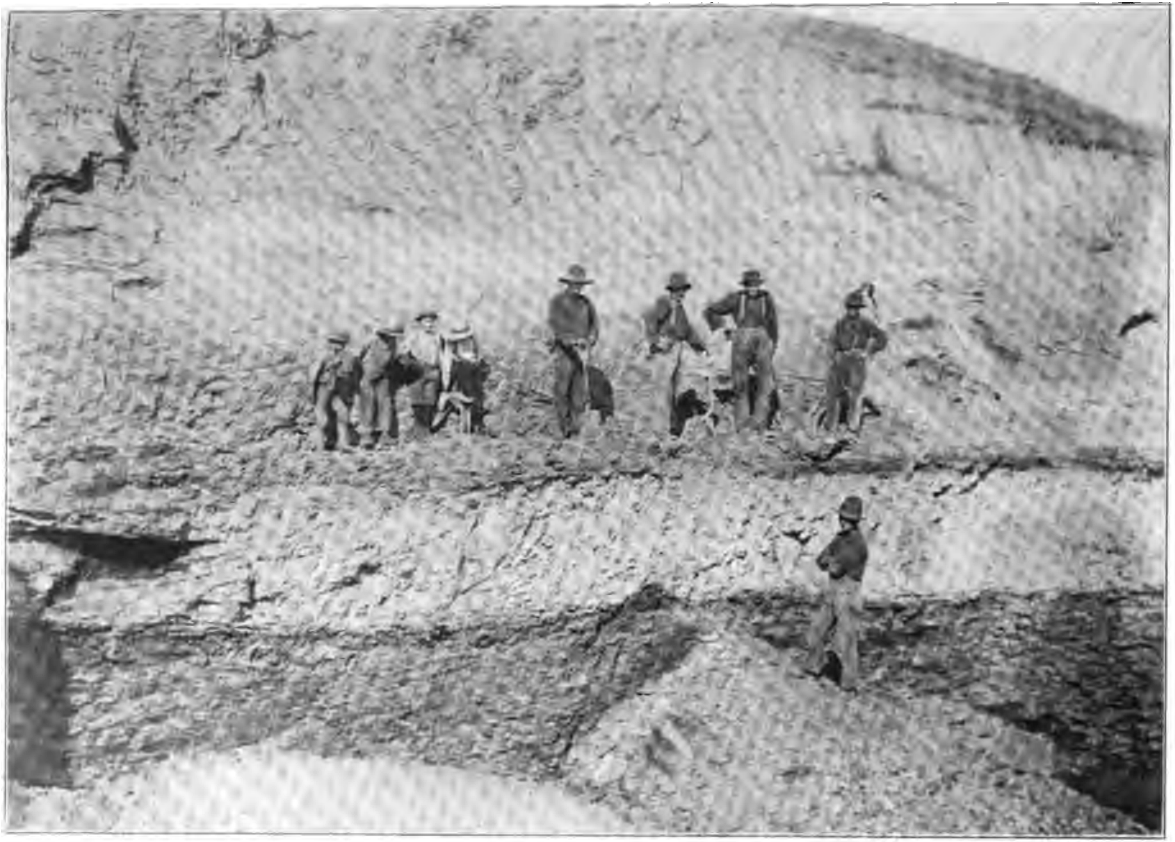
* The Western Interior Coal Fields, H. Foster Bain, Extract from the Twenty-second Annual Report, 1900-1901, part III.



Lignite in the Pit of the Dickinson Fire Brick Company. The Upper Clay Is Used for Brick While the Lignite is Used for Fuel in the Kilns.

PHYSICAL PROPERTIES OF THE LIGNITE COAL.

Moisture.—In a far larger measure than is the case with bituminous coal, the physical properties of lignite must be kept in mind in considering its fuel value. A series of analyses subsequently quoted show that lignite fresh from the mine contains 30 per cent of moisture, and in this respect samples taken from various parts of the state differ but slightly. When shipped under ordinary conditions and in the common manner, the lignite reaches the engine room with nearly all of its moisture. Small samples that are more or less exposed to the air for two months reach the laboratory with from 10 to 20 per cent of moisture, as shown by the subsequent tables which give analyses of specimens in connection with which no special effort was made to prevent drying.

The expense of shipping this moisture and its effect on the heating properties of the lignite are points worthy of careful study and experiment. The general opinion of those burning lignite is that if the lignite in drying did not fall to pieces, becoming so fine that it is apt to go through the grates, there would be great economy in burning it in that condition, and that in those devices where powdered or fine coal is used the dry lignite presents a material saving over the "green." Theoretically it would seem that this should be the case, for the heat necessary to volatilize the 30 per cent of moisture would be saved, and there is no apparent reason for a material loss of the volatile gases in drying.

In any case, if the coal could be dried before shipping and economically burned after drying, the freight charges would be reduced nearly one-third. No practical method of drying the lignite on a large scale has as yet been devised, and the undertaking will probably prove a difficult one.

The so-called slacking of lignite is the process of crumbling that it undergoes when drying. It probably loses none of its fuel value in consequence, and there is probably a gain in this respect due to the absence of the moisture.

Special conditions are necessary, however, to burn this fine coal advantageously, the danger being that it fall through the grate or be blown out through the stack. When burned in ordinary stoves and on coarse grates under boilers, the green, lump lignite is preferable With automatic stokers the coal is commonly preferred in a fine state, and they seem specially adapted to the use of lignite.

The Woody Structure of lignite is one of its characteristics. Often slabs and logs occur in the seam, which preserve nearly every detail of their original structure. When a seam is made up of this material, with no admixture of foreign matter, it is tough and compact and furnishes fuel of excellent quality. The prevailing color is brown, though some seams appear a dull black. When exposed to the air for a long time, thin bands become glossy black, resembling jet, and burn like pitch.

A layer of "slack" often forms the top of a lignite seam, sometimes attaining a thickness of eight feet. It seems to be lignite which has decayed in the air while the lower part of the seam was preserved under water. Its fuel value is probably low. An analysis gives 22 per cent of ash. Often an entire seam is made of this "slack" coal, though such seams are usually thin. In prospecting, it is sometimes difficult to determine whether the slack exposed at the surface is due to the disintegration of a good seam or whether the whole seam is slack. In general, it may be said that if the quality does not materially improve on drifting in six feet the entire seam is soft.

In connection with a briquetting device, this soft or slack lignite may be utilized, but at present it has little worth.

The following tables summarize the results of analyses that have been previously given in the county reports. A description of the locality from which the samples were taken may be found by referring to the index. In each case the moisture was driven off and its amount computed, and the fixed carbon, volatile matter and ash reckoned on the dry basis.

In Table I great care was taken in nearly every case to bring the samples to the laboratory in just the condition that they left the mine, and the percentage of moisture is consequently high. In Tables II and III no special care was taken to prevent the samples from drying.

Table I.—Analyses showing moisture in material fresh from mine. Fixed carbon, volatile matter and ash computed on dry basis:

Mine and Location	Fixed Carbon	Volatile Matter	Ash	Moisture
Anderson mine, Stanley				
Jones mine, sixteen miles southwest of Balfour	53.77	37.72	8.51	21.73
From Missouri river, two miles west of White Earth creek	51.60	43.04	5.36	13.33
Rose Hill mine, fifteen miles southwest of Balfour	53.11	38.81	8.08	18.08

Mine and Location	Fixed Carbon	Volatile Matter	Ash	Moisture
Opening, eight miles north of White Earth	56.51	36.94	6.55	17.76
F. F. Alger mine, Stanley, Ward county	49.63	35.57	14.80	16.80
Pleasant Valley mine, Shell creek	55.09	39.89	5.02	17.06
Sikes' mine on the Little Knife	47.55	42.68	9.77	16.03
Bad Lands, six miles east of Ft. Berthold	47.38	42.75	9.87	14.64
Boyds' mine, Township 152, Range 94, Section 17	55.18	37.85	6.97	17.63
Nesson opening	60.38	36.09	3.53	19.97
Williams' opening, five miles south of White Earth	44.49	31.59	23.92	17.02
Gille-Miller mine	60.12	34.19	5.69	18.39
Sorenson mine, Township 162, Range 92, Section 32	60.95	34.12	4.93	19.42
Pony Gulch mine, sixteen miles southwest of Harvey	51.66	36.72	11.62	19.16
Leigh Ericson, Donnybrook	59.75	35.14	5.11	19.50
Lloyd Mining Co.	58.23	33.13	8.64	17.08
Scribner's mine	56.61	36.87	12.52	16.23
Drift, near railroad bridge near Burlingon	56.57	38.01	5.42	17.46
Turtle Gulch mine, Township 152, Range 81, Section 14	53.78	37.20	9.02	20.02
Wm. Lacy's land, Coal Harbor	53.43	39.14	7.43	18.51
Hanchett mine, southwest of Velva	53.60	40.14	6.16	16.69
Coal canyon, Billings county, thirty miles south of Medora	52.47	38.57	8.96	16.79
J. C. Gamels' ranch, Billings county, Township 133, Range 104, Section 20	55.90	37.59	6.51	18.24
Sentinel butte, Billings county	48.04	42.67	9.29	18.99
From 777 ranch on Little Missouri	43.47	34.55	21.98	14.54
The forty-foot seam, Township 135, Range 101, Section 31	51.79	38.69	9.52	13.70
Lower vein on Missouri river, three miles south of Williston	50.65	36.15	13.20	10.56
Twelve-foot seam, three miles east of Williston	54.38	36.37	9.15	11.25
Heatons' land, Township 145, Range 80, Section 29	54.59	39.49	5.92	11.04
Coal Lake mine, Township 146, Range 82, Section 22	55.73	38.74	5.53	11.23
Reiss mine, New England	53.03	38.39	8.58	24.46
Stone Bird mine, near Belfield	56.61	35.71	7.68	21.56
Number of samples in tables I and II, sixty.				
Average of these sixty give	51.21	35.63	8.50	.....

Samples gathered and analyzed during the year 1900. Dried before analyzing:

Locality—Name of Mine	Carbon	Volatile Matter	Ash
Kenmare, Wright mine	58.83	37.96	5.21
Kenmare, Wright mine	58.01	34.95	7.04
Kenmare, Wright mine	57.85	34.26	7.89
Kenmare, Wright mine	55.28	37.52	7.20
Kenmare, Smith mine	53.24	40.59	6.17
Kenmare, Smith mine	44.49	43.57	11.94
Kenmare, Kraus mine	48.98	43.63	7.39
Burlington, Mouse River Lignite Coal Co.	56.02	34.79	9.19
Burlington, Mouse River Lignite Coal Co.	55.18	37.00	7.82
Burlington, Mouse River Lignite Coal Co.	52.21	32.72	15.07
Wilton, Washburn Coal Co.	51.87	41.10	7.03
Wilton, Washburn Coal Co.	50.97	42.26	6.77
Wilton, Ecklund Coal Co.	53.75	41.62	4.63
Wilton, Ecklund Coal Co.	53.67	40.61	5.72
Wilton, Ecklund Coal Co.	50.47	42.41	7.12
Lehigh, Lehigh Coal Co.	49.22	42.63	8.14
Lehigh, Lehigh mine	46.50	43.57	9.93
Lehigh, Lehigh mine	51.60	39.99	8.41
Lehigh, Lehigh mine	48.24	40.87	10.89
Lehigh, Lehigh mine	48.53	44.32	7.15
Lehigh, Lehigh mine	51.80	41.58	6.61
Lehigh, Lehigh mine	51.30	40.97	7.73
Lehigh, Lehigh mine	54.06	37.06	8.88
Near Williston, Brown & French	51.80	43.98	4.22
Near Williston, Dahl mine	52.78	42.65	4.57
Near Williston, Dahl mine	49.73	43.08	6.29
Average of the twenty-six samples	52.08	40.33	7.50

Deductions from Analyses.—The method of analysis employed in the tables given above differs from that commonly used for lignites in computing the percentage of moisture first, and then, after expelling the moisture, in determining the amount of the other constituents. The percentage of fixed carbon, volatile matter and ash is made somewhat higher than when the undried coal is analyzed. The practical difficulty in bringing the lignite to the laboratory without partial drying, however, makes it much more practical to compute their composition on a dry basis.

Even when allowances are made for this method of computation, the percentage of fixed carbon is high enough, if this alone is considered, to prove these coals from the lignites and place them with the sembituminous or steam coals. The content of water, however, about 30 per cent, restricts them to the former class.

EVAPORATIVE TESTS

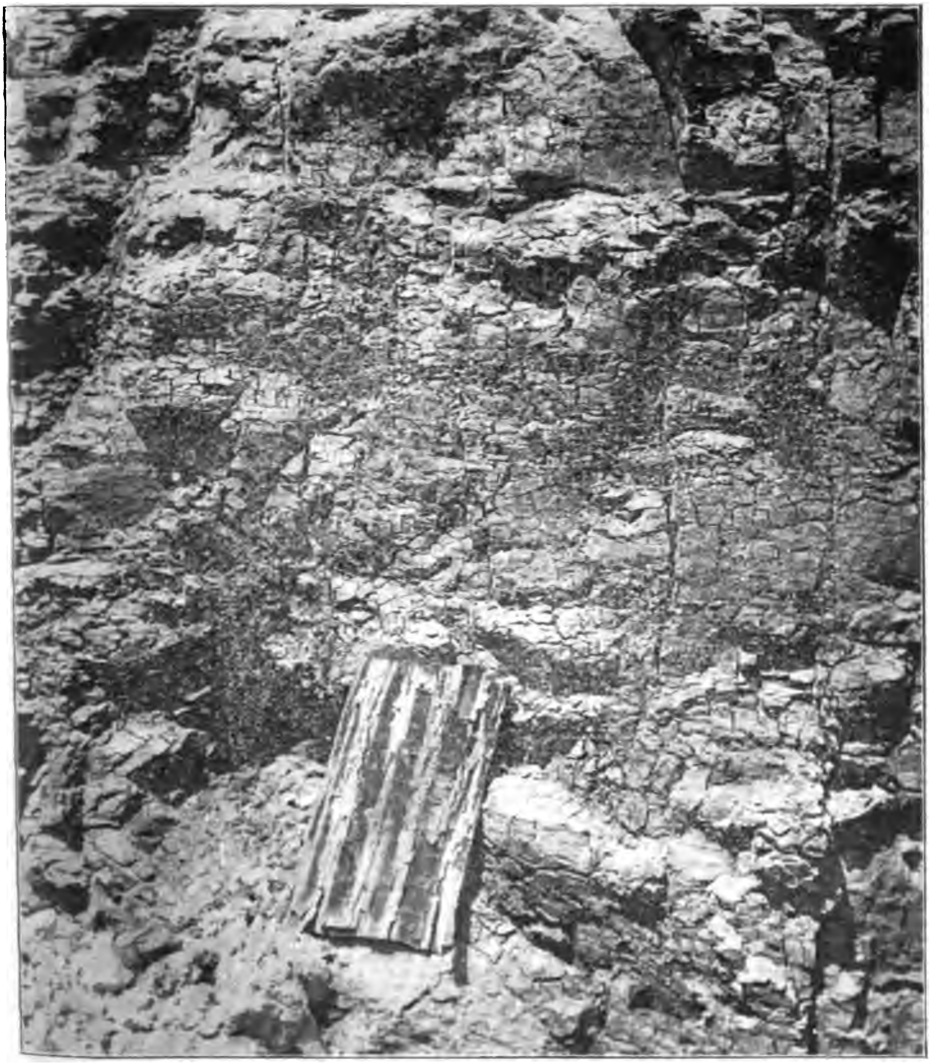
More satisfactory then either chemical or calorimetric tests are practical evaporative tests carried on with boilers of standard patterns. A number of such tests have been made, and in some cases, in the same boilers and under practically the same conditions, eastern coal has been tested, so that, knowing the price of each coal at the point given, it is possible to determine quite definitely the economy resulting from the use of lignite.

The following test was made at the asylum for the insame at Jamestown, by Chief Engineer Thos. Pettigrew, whose careful study of proper methods for burning lignite has greatly advanced the lignite industry. The statement introducing the test is written by him: .

"The use of lignite coal at this institution (asylum for the insane) started in 1890. Since that time we have used it continually for generating steam, and for the past eight years have used it exclusively for cooking in the general kitchen of the institution. Lignite coal can be burned in any furnace that burns hard or soft coal.

"The coal was burned on the soft coal grate and furnace up to the winter of 1894-5, when there was a change made in the furnace by arching over the grate with fire brick, and using the forced blast with a fan, which very much increased the value of the coal for making steam, by getting more benefit from the hydro-carbon of the coal.

"Eastern bituminous coal was tested against lignite in 1894, which gives the value of Dakota coal in comparison with the best bituminous coal in the market (which is Youghiogheny coal). I tested Youghiogheny coal first with the boilers before making any alteration for the lignite coal, and there was little difference between the tests of lignite coal. We find from our experience at this institution that the coal fresh from the mine gives us as good results as the coal when dry. One pound of lignite coal fresh mined will evaporate as much water as a pound of lignite dried."



The Slab in the Foreground Illustrates the Woody Structure Sometimes Found in Lignite. The Wall of Lignite Behind It Shows the Manner in Which It Checks on Drying.

UNIV. OF MICH.

The following table shows the result of the tests made here:

	Youghiogheny Coal	Lignite Coal
Date of test	Aug. 6, 1894	Aug. 8, 1894
Duration of test	7 hrs. 30 mins.	8 hrs.
Average temperature of feed water	74 Fahr.	74 Fahr.
Pounds of coal burned	1,400	3,370
Pounds of combustible	1,243	3,170
Per cent of ash	11.21	5.93
Pounds of coal burned per square foot of grate per hour	8.29	18.72
Total water evaporated at temperature of feed	8,837 lbs.	14,157 lbs.
Water evaporated in pounds, per pound of coal, actual condition	6.312	4.2
Water evaporated in pounds, per pound of combustible	7.1	4.46
Temperature of flue gases	510 Fahr.	510 Fahr.
Boiler 6 feet in diameter by 16 feet long with thirty four and one-half in. flues. Grate surface four ft. five in. by five ft. Coal three days from mine. Value of coal	1.00	.665

The cost of Youghiogheny lump at Jamestown was $6.80 per ton and of lignite $2.80.

Result of Evaporative Test Made by the Missouri River Milling Co., at Mandan.—Fuel, Lehigh lignite:

Duration of test	11 hours
Kind of furnace	Smith-White
Grate surface	30 square feet
Width of air space in grate	¼ inch
Water heating surface	1,549 square feet
Ratio of water heating surface to grate surface	51-1
Average steam pressure	104
Average temperature of feed water entering boiler	175 deg. F.
Total coal fed to furnace	12,221 pounds
Moisture in coal	23 per cent
Coal consumed per square foot of grate per hour	37 lbs.
Cost of coal delivered at mill, per ton	$1.60
Total cost of coal	$9.77
Total weight of water fed to boiler	5,635 lbs.
Water evaporated per hour from and at 212 degrees	5,554
Horse power developed	163
Cost of fuel for evaporating 1,000 lbs. of water	.1734 cts.
Average horse power of engine	190
Cost per horse power per hour	.0047

The mill has a capacity of 450 barrels of flour per day, and the cost of fuel when lignite is burned per barrel of flour ground is 4.46 cents.

Trial Test of Wilton Lignite Coal in the Fargo-Edison Co.'s Plant, January 9, 1901.—Duration of test, twelve hours. Time of test from 4 p. m. to 4 a. m., January 9, 1901:

Boilers used	Two 72-16 tubular, one 200 H. P. Heine water tube
Total heating surface	4,823 square feet
Total grate surface	88 square feet
Average steam pressure	83 lbs.
Average temperature of feed water	140 degrees
Total weight of coal fired	26,400 lbs.
Cost of coal per ton of 2,000 lbs. at boilers	$2.60
Total cost of coal	$34.32
Total weight of water pumped into boilers and apparently evaporated	97,500 lbs.
Water evaporated per lb. of coal from average pressure and temperature	3.7 lbs.
Equivalent evaporation from and at 212 degrees	4 1 lbs.
Coal burned per square foot of grate per hour	25 lbs.
Cost of fuel to evaporate 1,000 lbs. of water	.352 cents
Per cent of moisture in coal	30 per cent
Per cent of refuse in coal	3½ per cent

Trial Test of Youghiogheny Screened Lump Coal at the Fargo-Edison Co.'s Plant.—Duration of test, twelve hours, from 4 p. m. to 4 a. m., January 10, 1901:

Boilers used	one 72-16 tubular, two 200 H. P. Heine water tube
Grate surface	64 square feet
Water heating surface	3,323 square feet
Average steam pressure	83 lbs.
Average temperature of feed water	147 degrees
Total weight of coal fired	11,480 lbs.
Cost of coal per ton of 2,000 lbs. at boiler	$5.42
Total cost of coal	$31.11
Total weight of water pumped into boilers and apparently evaporated	93,200 lbs.
Water evaporated per lb. of coal from average temperature and pressure	8.12 lbs.
Equivalent evaporation from and at 212 degrees	8.90 lbs.
Coal burned per square foot of grate per hour	15 lbs.
Cost of coal to evaporate 1,000 lbs. of water	.3328 cents
Per cent of moisture in coal	
Per cent of refuse in coal	

While the tests just given show that at the prices quoted eastern coal has a slight advantage over lignite, as a matter of fact the Fargo-Edison company has obtained prices on lignite delivered at their plant which renders it a matter of great economy to use lignite, and all of their power is developed with the use of this fuel.

Boiler Test Taken at the North Dakota Agricultural College, March 8, 1902, by Class in Steam Boilers:

Duration of test	8.5 hrs.
Average atmospheric pressure	28.5 in.
Gauge pressure	73.8 lbs.
Temperature of feed water	144 degrees F.
Kind of fuel	"White Ash" lignite
Percentage of moisture in coal	36 per cent

No.		
1.	Descripton of boiler: Common fire tubular boiler, with sixty-two flues, three inches in diameter, sixteen feet long; diameter of shell, sixty inches.	
2.	Water heating surface	962 square feet
3.	Ratio of water heating surface to grate surface	.025
4.	Pounds of coal burned	3,907
5.	Unburned fuel	None
6.		
7.	Average coal burned in fifteen minutes	144.91 lbs.
8.	Total refuse from coal	168 lbs.
9.	Total combustible	2,314.5 lbs.
10.	Average combustible for fifteen minutes	68.05
11.		
12.		
13.	Quality of steam (saturated steam taken as unity)	97 per cent
14.	Total water pumped into the boiler	1,236.5 lbs.
15.	Water apparently evaporated per pound of fuel burned	3.16
16.	Water actually evaporated, corrected from moisture	11,994 lbs.
17.	Equivalent water evaporated into dry steam from and at 212 degrees F	13,228 lbs.
18.	Equivalent evaporation into dry steam from and at 212 degrees F. per pound of dry coal burned	3.385 lbs.
19.	Coal burned per square foot of grate surface, per hour	18.38 lbs.
20.	Water evaporated from and at 212 degrees F. per square foot of heating surface	1.606 lbs.
21.	Equivalent evaporation into dry steam into pound of combustible	5.68

22. This is the calorimeter test for coal.

	Per Cent
Average ash	9.03
Combustible	90.97

GAS ANALYSIS	Per Cent
CO_2	7
O	6
CO	1.05

Test conducted by Lewis Larson.

In these tests natural draft only was used.

Test at State University.—On November 17, 1902, a preliminary test of lignite coal from the mine of the Kenmare Coal Co. was made under boilers 1 and 3 of the State University heating plant. During the coming winter more elaborate tests will be made under boilers provided with the lignite fire brick arch and under boilers without arches,, which it is hoped will settle the disputed question as to the real worth of these arches. For the test given below a steam calorimeter was not available, and the water fed to the boiler is assumed to have been evaporated. The boilers are fire tubular, diameter of shell fifty-four inches. Each contain forty-eight sixteen-foot flues with inside diameter of three and a half inches, and each contains 841.76 square feet of heating surface. They are provided with the lignite fire brick arches, and the test was made under forced draft from a fan.

Duration of test	12½ hours
Percentage of moisture as shown by four days' drying	10 per cent
Percentage of ash	7.828 per cent
Evaporated per pound of fuel from and at 212 degrees Fahr	4.307 lbs.
Evaporated per pound combustible (coal minus ash and water) from and at 212 Fahr	5.242 lbs.

With boiler and grate conditions about like those used in the test at the asylum for the insane, already quoted, three Iowa coals tested at Des Moines gave per pound of coal a water evaporation of from and at 212 degrees F. of 5.44, 5.21 and 6.52 pounds respectively. Four standard Missouri coals gave 6.84, 6.27, 6.23 and 5.86 pounds respectively.* Comparing the results obtained with lignite with these—taking the evaporative powers of lignite at 4.1 pounds, which is conservative—the lignite appears to be worth 75 per cent of the Iowa coal, and 70 per cent of the Missouri product.

Locomotive Tests.—The question of fuel for locomotives in North Dakota is an important one. The lignite has generally been regarded as too light a fuel, and other coals are commonly used. An engine was especially constructed by the Baldwin Locomotive works for the Bismarck, Washburn & Great Falls railroad for the purpose of using lignite as fuel. The engine has compound, double entry cylinders, the high pressure fourteen inches in diameter, and the low twenty-four, with twenty-six-inch stroke, drive wheels fifty inches in diameter. The waist of boiler is sixty-eight and three-fourths inches, number of tubes 270, two inches in diameter and sixteen and one-half feet long. The fire box is ninety-six inches long and eighty-four inches wide. The fire is drawn back over a brick arch, preventing the drawing of the fuel out by too strong a draft, and the arch becoming incandescent aids in the burning of the volatile gases. The chief characteristic of the engine is the longer and wider fire box, the brick arch which is in use for ordinary coal being merely accentuated.

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* The Western Interior Coal Field, 22d Annual Report, U. S. Geological Survey, p. 349.

The following account of the testing of the locomotive was written by Mr. E. H. Walker of the Washburn road and published in the Bismarck Tribune:

The recent test of lignite as a fuel for engines on the Northern Pacific road, in hauling heavily loaded freight trains over the main line of that road, was a successful one in every particular. The test proves that with engines constructed for the consumption of lignite coal this fuel is available for use on roads at a great saving over the fuel at present in use. Railroad men from all parts of the country are interested in the test, which is the first practical application made of the fuel in an engine especially designed for its use. The principal objection in the past, when tests of lignite coal have been made in railroad locomotives, has been that the draft has lifted the fire out of the fire box and carried the live coals through the flues and out of the stack, rendering it difficult to keep a fire. This has been overcome in the construction of engine No. 3, the Washburn road engine with which the recent test was made. The engine has a brick arch over the fire box, which prevents the lifting of the fire, which passes around the end of the arch, and then through the flues, keeping a steady and hot flame. All gases from the coal rise to the top of the arch, where they are consumed. As a result, there is little smoke from the engines, and what smoke escapes is light in color, and does not roll forth in thick, black clouds produced by the consumption of the bituminous coal with the standard engines.

The officials of the Northern Pacific road have prepared the figures of the tests made between Mandan and Jamestown both on the down trip and the return, and they have been certified to. The following are the official figures for the first trip, from Mandan to Jamestown, February 19:

Distance, 106 miles.

Train left Mandan, 9:05 a. m.

Arrived at Jamestown, 7:30 p. m.

Actual running time, five hours, thirty-five minutes.

Average speed, twenty miles per hour.

Average steam pressure, 198 pounds.

Amount of lignite coal consumed, eighteen tons, 500 pounds.

Tonnage behind tender, 1,316 tons.

Number of cars, forty-three loads.

Estimated number of tons of eastern coal to make trip same run and train, eight tons.

Cost per ton, eastern coal at Mandan, $4.03.

Total cost of eastern coal for trip, eight tons, $32.24.

Cost of lignite coal, eighteen tons, 500 pounds, at $1 per ton, $18.25.

Saving in favor of lignite, $13.99, or 43.4 per cent.

On the following day a test trip was made west bound with the same engine and an increased load, and the following figures are given:

Distance, 106 miles.

Left Jamestown, 10:10 a. m.

Arrived at Mandan 1:30 a. m.

Actual running time, seven hours, thirty minutes.

Average speed, twelve miles per hour.

Average steam pressure, 196 pounds.

Amount of coal consumed, twenty-four tons, 500 pounds.

Tonnage behind tender, 1,564 tons.

Number of cars, forty-one loads, five empties.

Number of tons of eastern coal to make same trip with same train, eleven tons.

Cost of eastern coal, $44.33.

Cost of lignite, $24.25.

Saving, $20.08, or 45.3 per cent.

The test was made with engine No. 3 of the Bismarck, Washburn & Great Falls road. The engine was made to order for the Washburn road by the Baldwin Locomotive works, designed especially for the burning of lignite coal. It is a Vauclain compound six-wheel coupled, with trailing truck and fifty-four-inch drivers, 200 pounds steam pressure, and 24x17x26 cylinder.

It has a wagon top boiler, and the weight of the engine is 156,000 pounds, and the weight on the drivers 120,000 pounds.

The test was supervised by Master Mechanic Currie, Traveling Engineer Larrison and Trainmaster Blewett for the Northern Pacific road, and Master Mechanic Burrows and Traffic Manager Walker for the Washburn road. The tender was coaled at Bismarck and Dawson on the down trip and at Medina and McKenzie on the return trip.

The test will be followed up with others, and if the same ratio of saving is proven, the Northern Pacific will probably take up the matter of coaling in this section of the country with lignite, at least on part of its service. A demonstrated saving of over 40 per cent on fuel is an item that will be of considerable consequence in considering the availability of lignite coal as fuel.

A more detailed statement of certain phases of the tests is given below:

Trip west bound, February 20th, Jamestown to Mandan:

Average train tons	1,564 tons
Number of cars in train	40 loads, 5 empties
Amount of coal consumed. (This includes the amount used in firing up engine at Jamestown and in yard, which is estimated at two and a half tons)	25 tons, 500 lbs.
Average steam pressure maintained	188.28
Maximum	200 lbs.
Minimum	140 lbs.
Average water level	4.53 gauges
Maximum	3 gauges
Minimum	½ gauge

Average cut-off	4.53 notches
Maximum	10 notches
Minimum	1 notch
Pounds of water evaporated per pound of coal	2.118 lbs.
Running time, including delays	15 hours, 42 minutes
Running time not including delays	8 hours, 2 minutes

NOTE—Steam pressure and water level noted every five minutes when engine pulling train.

NOTE—Reverse lever is arranged with ten notches from center, in forward gear; blank space of three and one-half notches and one-half notch from center to first notch and one notch per inch thereafter.

NOTE—Distance from Mandan to Jamestown, 106 miles.

NOTE—Grade track rated at 4-10ths grade.

NOTE—Weather favorable; rails dry; temperature about freezing; engineer and fireman used were totally unfamiliar with the Northern Pacific track.

Trip east bound, February 19th, Mandan to Jamestown:

Average train tons	1,288 tons
Number of cars in train	42 loads
Total amount of coal consumed. (This includes amount used in firing up and running engine six miles to deliver at Mandan. Estimated quantity for this performance three tons)	18 tons
Average steam pressure maintained	195.15 lbs.
Maximum	200 lbs.
Minimum	160 lbs.
Average water level in boilers as shown by gauge cocks	2.88 gauges
Maximum	3 gauges
Minimum	½ gauge
Average cut-off as shown by reverse lever quadrant	2.5 notches
Maximum	9 notches
Minimum	1 notch
Pounds of water evaporated per pound of coal	2.403 lbs.
Running time, including delays	11 hours, 30 minutes
Running time, not including delays	5 hours, 57 minutes

Practical Tests in Mill and Electric Plants.—Two large flouring mills at Mandan and Jamestown use lignite exclusively for fuel, the freight rate to Mandan on lignite being somewhat less than that to Jamestown. The cost of fuel per barrel of flour at both of these mills is 4½ cents. A description of the boiler and grates used by the Missouri Valley Milling Company at Mandan has already been given.

The plant of the Russell-Miller Milling Company at Jamestown, a 500-barrel mill, uses a single boiler, seventy-two inches by sixteen feet, with seventy-two four-inch flues. Shaking grates giving an area of thirty-six square feet, with one-half inch air spaces, are used. Forced draft secured by a fan is employed. One hundred and seventy horse power is maintained for twelve hours with the use of 7,600 pounds of Washburn lignite. The engine is a Corliss, compound condensing, rated at only 165 horse power. A careful test has shown that 3.73 pounds of Wilton lignite will maintain one horse power per hour. With lignite at $2.45 at the mill the cost of making a barrel of flour is 4.5 cents.

The Hebron Roller mill burns four tons of lignite in twenty-four hours with an output of 100 barrels of flour, besides custom work. Natural draft and ordinary grates are used.

The Kenmare Roller mill, using a boiler sixty-six inches in diameter and sixteen feet long, and grate with three-eighth-inch openings, uses 161 pounds of slack lignite per hour to generate forty horse power, the steam pressure being sixty-five pounds.

The Washburn Roller mill maintains thirty horse power for twelve hours with one and one-half tons of lignite. The boiler is twelve feet by thirty-six inches, and the engine small and crowded.

The New Salem Roller Mill Co. is operating a 125-barrel mill to its full capacity. The boiler is fourteen feet by fifty-two inches, and the engine is rated at seventy-five horse power. Forced draft is employed. In twelve hours 3,700 pounds of lignite are burned.

The electric plant at Dickinson burns lignite under a boiler seventy-two inches in diameter and seventeen feet long, using ordinary grates and forced draft, the fan being driven by a two horse power motor.

The Minot Electric Light Company employs two boilers sixteen feet long and fifty-four inches in diameter. Fifty horse power is maintained for ten hours with two tons of green lignite. Natural draft is used, and the engineer does the firing also.

The Bismarck Electric plant supplies that city with light at an expense of from two to three tons of lignite per night, The streets are well lighted, and the amount of custom lighting is large.

The United States Weather Bureau at Bismarck formerly burned anthracite wholly at $10.50 per ton, from September to May, at an average monthly expense of $50 for the two large buildings. Appliances for burning lignite were introduced and the fuel bill in consequence reduced to $16 per month, the cost of lignite being about $2 per ton.

The Power House at the State University, Illustrating Forced Draft Appliance.

Lignite for Burning Brick.—Since the lignite occurs with very valuable deposits of clay, it furnishes the natural fuel for burning brick in this state. It is used for this purpose at Dickinson, Williston, Washburn, Burlington, New Salem, and a number of the newly organized mining companies propose to undertake the manufacturing of brick as well.

The Dickinson Pressed Brick and Fire Clay Company burns 1,000 red brick at a temperature of 1,500 degrees with 1,500 pounds of lignite. Both forced and induced draft is used in their kilns.

The Bowser Brothers' brick yard at New Salem and the Davis yard near Burlington obtain about the same results, namely, burn on the average 1,000 brick with 1,500 pounds of lignite. At these yards natural draft only is used.

HOW TO BURN LIGNITE

For Steam Purposes.—Automatic Stokers.—In plants where considerable quantities of lignite are used, automatic stokers with forced drafts give most satisfactory results. At the Fargo-Edison Electric plant, at Fargo, stokers which burn the refuse from the Washburn mine, which consists of the cuttings of the mining machines and the fine coal incidental to blasting, are in successful operation, and demonstrate clearly the ability of lignite to compete with eastern coal in the Red river valley. The lignite, varying in size from dust to fragments of half a pound weight, is shoveled into hoppers and fed into the furnace by a screw eight or nine inches in diameter, the flanges being six inches apart. Forced draft is introduced into the ash pit. The cost of firing is greatly reduced, and the fires are exceedingly uniform. Other forms of stokers are doubtless practical.

When an economic method of drying the lignite before shipping from the mine is found, it will be possible to save 30 per cent of the freight. With automatic stokers, the fact that it is reduced to fragments in the process of drying will be desirable.

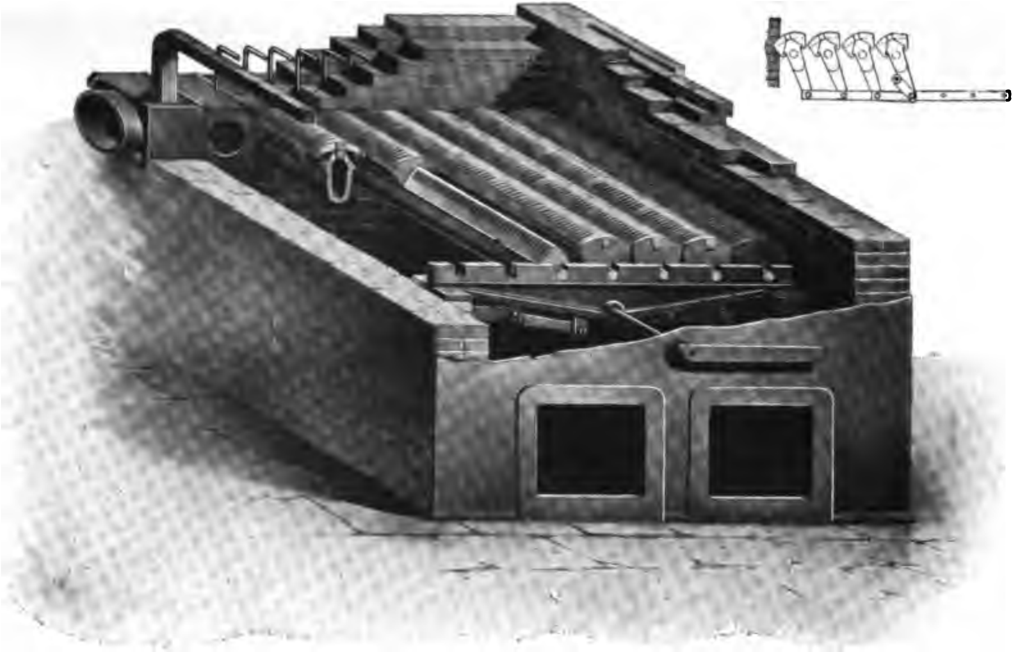
Forced Draft and Arches.—On account of the gases that lignite contains, volatile at a moderate temperature, special devices have been introduced in furnaces intended for its consumption in which these gases shall be promptly raised to the temperature necessary to secure their complete combustion. For this purpose an arch of fire brick is frequently built over the front of the fire box, which becoming intensely hot secures the combustion of the gases that come in contact with it. That it is useful for this purpose there can be no question. The question remains as to whether it adds to the efficiency of the coal, since it shuts off a portion of the boiler from direct contact with the fire and interferes with firing when fuel is fed with a shovel. To a certain extent the bricks themselves conduct heat to the boiler. The question of their worth is not fully demonstrated, and the cost of their installation is considerable. Many persons who are using them consider them of great value.

Forced draft is desirable if the plant is large, but lignite is giving excellent results in a number of plants where natural draft only is used. With forced draft a short stack is sufficient and this saving over the construction of a tall chimney is often enough to pay for the installation of the fan. The forced draft is introduced into the center of the ash pit and there caused to spread out, so that it reaches all parts of the grate uniformly. Induced draft is not recommended for any purpose in connection with lignite, though a combination of forced and induced drafts seems to solve satisfactorily certain difficulties in burning brick.

Plate XXXV illustrates the power house at the University heating and lighting plant. The fan A is connected by the pipe B, which collects the hot air that accumulates above the boilers. This hot air is introduced under the gates at C, the amount entering being subject to a regulator. This regulator is connected with the steam pipe E, which feeds the steam to the engine, and also with the water pressure. When the steam pressure rises above the desired point, the engine running the fan is automatically shut off and the drafts are closed at the same time. When the steam pressure falls below the proper point, the valve which allows the steam to enter the engine operating the fan is opened mechanically, and the forced draft is renewed. The grates are of the fine, rocking fork pattern, and may be operated without opening the furnace doors.

A hollow rocking grate, in which the forced draft passes through the grates and out into the furnace through narrow slits, uniformly distributed, is giving satisfaction for burning lignite at Moorhead, Fargo, Valley City and Mandan. This grate is illustrated in plate XXXVI.

Firing Lignite Under Boilers Where Forced Draft is Not Used.—Very satisfactory results are being obtained with lignite



Hollow Grates Adapted to Forced Draft.

and natural draft at the Minot electric light plant, the Kenmare roller mill and similar institutions throughout the state. With natural draft a large boiler and grate surface are desirable, though not absolutely essential, and more experience in firing lignite is necessary. The fires should not be allowed to fall off, for if green lignite is thrown in the furnace when the steam is falling it acts like a blanket and temporarily smothers the fire. Fuel should be added when the fire is high, and by the time the steam guage begins to drop the fresh lignite has been dried and is ready to burn. It is a good plan to fire but one side of the furnace at a time.

Lignite for Domestic Purposes.—Nearly every large stove factory in the country is at present putting on the market a stove especially adapted for burning lignite, and many of these stoves are highly successful. The odor from partially consumed gases is wholly done away with, and an abundance of heat, easily regulated and maintained, is secured. A smouldering fire may be kept for a long time, either in kitchen range or heater, which, by a proper adjustment of draughts, may be quickly aroused to great activity.

In stoves that are designed for anthracite lignite will burn, and those who do not find it practical to discard old stoves for those especially planned for lignite are not placed at a great disadvantage by its use.

Briquetting Lignite.—In this connection the lignite presents great possibilities. Briquettes are concentrated lignite, dried, clean and of convenient size to handle. They are fuel bricks, weighing from half a pound to two or more pounds, and when properly made will stand exposure to any sort of weather. They are a favorite form of fuel in all parts of the old world, where lignite is used in large quantities.

Condensed fuel in this form is desirable when the item of transportation is a large one in the fuel problem, as is especially true in the North Dakota lignites. In the form of briquettes it may be possible to bring the lignite even from the western boundary of the state to market. Briquettes will burn nicely in any stove in which wood or bituminous coal can be burned, and while they are used in Europe for all purposes, in our state it may be predicted that they will first be put on the market for domestic use. In the preparation of briquettes the lignite must first be finely crushed and dried. According to German practice,* the crushed coal is passed through warmers, through which it is moved mechanically, obtaining a temperature of 100 degrees F. Thence it goes into warm storage bins where its temperature is raised to 180 degrees F. During this process it loses two-thirds of its moisture. It is found necessary to bring the temperature back to 100 degrees F. before it goes to the presses. The fine dried coal may be consolidated into briquettes mechanically, by pressure alone, or a "binder" in the shape of some cement may be used. Tar, pitch and asphalt are common binders, which add to the combustion of the briquette. Milk of lime is an excellent binder, which, while adding nothing in the way of inflammable matter to the briquette, is inexpensive and may be used in such small quantities as not to interfere with its burning.

In a new community the scarcity and expense of labor is the great factor which must be considered in planning manufacturing enterprises, and the briquetting of lignite is no exception. With the increase in population this industry is certain to come to the front, for the mechanical difficulties which it presents are already in a fair way to be solved. A number of persons and companies have attacked the problem vigorously and are meeting with success. The following letter from Hon. W. D. Washburn states concisely the outcome of one of the most important series of experiments:

MINNEAPOLIS, Minn., September 24, 1902.

Mr. Frank A. Wilder, Director State Geological Survey, Grand Forks, N. D.:

DEAR SIR: I am in receipt of your letter of the 22d inst. I have been giving, in the past two years, a great deal of attention to the matter of briquetting lignite coal from North Dakota. I have investigated the subject in many directions, but as yet have reached no definite conclusions or results. Parties in Pittsburg have been experimenting on this matter for the last year and a half, or nearly two years. The great difficulty in briquetting this coal, you understand, is in the matter of securing a binder that will make it possible to briquette this coal at an expense that will make it commercially feasible. The Pittsburg people have been giving great encouragement in briquetting this coal without any binder, but as yet have not succeeded. There are many objections to using a binder. Among them the large cost and also making the briquettes disagreeable in smoke and odor.

I have, within the past few days, received a letter from a party in

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* Die Press Kohlen-Industrie, Ein Handbuch der Stein Kohlen und Braun Kohlen Briquettirung von Eduard Preissig, Bergdirector in Prag.

New York, sending me samples of briquettes, and this seems the most promising of any that has yet turned up. The briquettes sent in the samples appear to be very satisfactory, more so than any I have ever seen made from this coal. I am sending him another lot of coal from which he will make a greater number of briquettes than already sent. I have great hopes that something may come from this direction. I shall be very glad to give you all the information that I secure from time to time.

Yours sincerely,
W. D. WASHBURN,
President.

SIGNIFICANCE OF THE LIGNITE TO THE STATE

Forests do not exist in North Dakota, though the valleys of the Red river, the Mouse, the Cheyenne, the Missouri and smaller streams are well wooded, and the term timber land may fairly be applied to certain parts of the Turtle and Pembina plateaus. Large trees are generally confined to the flood plain, though at times they are found on the first terrace as well, while in the tributary coulees and ravines groves are nearly always found on the side protected from the prevailing wind. About some of the lakes there are fine groves that have furnished fuel in considerable quantities. Though wood is still cut for fuel along some of the larger streams, the supply grows less every year, and the price rises proportionately. Near the eastern boundary of the state wood from Minnesota is used, but the cost is rapidly increasing.

For the western part of the state wood does not enter as a factor into the fuel problem, while in the Red river valley the limit of the wood supply is easily in sight. The question of the coal supply, therefore, becomes a vital one to the rapidly growing state.

POSITION OF THE STATE WITH REFERENCE TO THE EASTERN AND WESTERN BITUMINOUS AND ANTHRACITE FIELDS

The Red River Valley.—Coal from the eastern fields reaches North Dakota from Duluth, to which point it is shipped by boat at low rates. The reloading and long haul across Minnesota have added materially to its cost when it reaches the Red river valley, while a considerable addition to its selling price must again be made to defray freight charges when it reaches the center of the state.

Ordinarily, Hocking valley coal, when contracted for in considerable quantities, costs from $5.25 to $5.50 per ton in the Red river valley. The selling price of Youghiogheny coal is about the same. Lignite throughout the Red river valley sells at about $3 though one or two large consumers have secured figures considerably below this. At $3 a ton the economy of lignite for steam purposes in this region is not wholly demonstrated At $2, however, there is a decided advantage in its favor. For stoves and ranges the lignite may be used advantageously at a higher price. It is but a question of time, however, till cost of production will be cheapened, and a large volume of trade will justify lower freight rates, assuring the use of lignite, even in western Minnesota, for all purposes.

Lignite Shipments to Minnesota.—For domestic purposes lignite is now being shipped in considerable quantities to Minneapolis and St Paul, and the demand from these centers is destined to increase. Its great convenience for use in ranges greatly adds to its value. When the problem of briquetting the lignite is solved, it will be practical to extend the market even farther east. The briquette is a concentrated fuel, thoroughly dry and clean and convenient to handle, and justifies shipment to more distant points than does the raw material.

The James River Valley.—Some fifty miles before the James river valley is reached the line beyond which under present conditions eastern coal can in any way compete with lignite is passed, and in the valley itself conditions are strongly in favor of the North Dakota fuel. At Jamestown, under favorable conditions, Youghiogheny coal costs from $6.80 to $7 a ton while lignite retails at less than $3. This wide stretch of fertile and prosperous country is destined to form a constantly growing market for the coal mined in the western half of the state.

The Missouri Valley.—Before the Missouri is reached, the lignite area is entered, and so fully is the worth of the native fuel realized that eastern coals are rarely quoted at Bismarck. Red Lodge coal mined in Montana is used by the Northern Pacific railroad, but on account of freight rates is not offered for sale in North Dakota. Sand Coulee coal, also a Montana product, is burned by the Great Northern locomotives, but on both of these roads lignite is used in the western half of the state for their engines at pumping stations.

Freight Rates on Lignite.—There is no greater factor in the problem of the development of the lignite industry than the cost of transportation. The rates as now established on the roads entering the lignite area are given below:

Northern Pacific Railway Company in Connection With Bismarck Washburn & Great Falls Railway from Wilton, N. D., to Stations in North Dakota and Minnesota:

	Rate in Cents Per Ton of 2,000 Pounds
Apple Creek, N. D.	$ .68
Steele, N. D.	.90
Jamestown, N. D.	1.10
Carrington, N. D.	1.30
Leeds, N. D.	1.54
Grand Rapids, N. D.	1.30
LaMoure, N. D.	1.30
Edgeley, N. D.	1.38
Oakes, N. D.	1.38
Wyndmere, N. D.	1.58
Great Bend, N. D.	1.69
Wahpeton, N. D.	1.69
Breckenridge, Minn.	1.69
Fergus Falls, Minn.	1.74
Sheldon, N. D.	1.50
Sanborn, N. D.	1.22
Rogers, N. D.	1.26
Hannaford, N. D.	$1.30
McHenry, N. D.	1.46
Valley City, N. D.	1.26
Tower City, N. D.	1.30
Casselton, N. D.	1.42
Lucca, N. D.	1.54
Dalrymple, N. D.	1.42
Fargo, N. D.	1.50
Moorhead, Minn.	1.50
Glyndon, Minn.	1.54
Fertile, Minn.	1.74
Crookston, Minn.	1.78
Red Lake Falls, Minn.	1.78
East Grand Forks, Minn.	1.85
Grand Forks, N. D.	1.85
Grafton, N. D.	1.96
Pembina, N. D.	2.06

Northern Pacific Railway Company in Connection With Chicago & Northwestern Railway:

From Bismarck, N. D., to	Rate in Cents Per Ton of 2,000 Pounds
Ludden, N. D.	$1.30
Hecla, S. D.	1.34
Aberdeen, S. D.	1.38
Mansfield, S. D.	1.54
Redfield, S. D.	1.64
Faulkton, S. D.	$1.74
Frankfort, S. D	1.69
Groton, S. D.	1.78
Watertown, S. D.	1.83

Northern Pacific Railway Company from New Salem, Blue Grass, Sims and Lehigh, N. D., to Stations in North Dakota and Minnesota:

	Rates in Cents Per Ton of 2,000 Pounds from			
To	New Salem	Blue Grass	Sims	Lehigh
Dickinson, N. D.	$ .90	$ .90	$ .86	$ .30
Hebron, N. D.	.68	.68	.59	.59
Glenullin, N. D.	.59	.59	.50	.75
Mandan, N. D.	.59	.59	.68	.98
Bismarck, N. D.	.59	.68	.68	1.02
Jamestown, N. D.	1.10	1.14	1.14	1.42
Carrington, N. D.	1.30	1.30	1.30	1.58
Sykeston N. D.	1.34	1.34	1.38	1.67
Leeds, N. D.	1.54	1.58	1.58	1.78
Grand Rapids, N. D.	1.30	1.30	1.30	1.58
LaMoure, N. D.	1.30	1.34	1.34	1.64
Edgeley, N. D.	1.38	1.42	1.42	1.69
Oakes, N. D.	1.38	1.42	1.42	1.69
Wyndmere, N. D.	1.58	1.64	1.64	1.80
Great Bend, N. D.	1.69	1.69	1.69	1.85
Wahpeton, N. D.	1.69	1.69	1.71	1.87
Breckenridge, Minn.	1.69	1.69	1.71	1.87
Sheldon, N. D.	1.50	1.50	1.54	1.75
Sanborn, N. D.	1.22	1.22	1.26	1.50
Rogers, N. D.	1.26	1.26	1.26	1.54
Hannaford, N. D.	1.30	1.34	1.34	1.64
McHenry, N. D.	1.46	1.46	1.50	1.74
Valley City, N. D.	1.26	1.26	1.30	1.58
Casselton, N. D.	1.42	1.42	1.42	1.69
Lucca, N. D.	1.54	1.54	1.54	1.75
Dalrymple, N. D.	1.42	1.42	1.46	1.71
Fargo, N. D.	1.50	1.50	1.50	1.74
Moorhead, Minn.	1.50	1.50	1.54	1.75
Glyndon, Minn.	1.54	1.54	1.54	1.78
Fertile, Minn.	1.74	1.74	1.75	1.92
Crookston, Minn.	1.78	1.80	1.80	1.96
Red Lake Falls, Minn.	1.78	1.80	1.80	1.96
East Grand Forks, Minn.	1.85	1.85	1.87	2.03
Grand Forks, N. D.	1.85	1.85	1.87	2.03
Grafton, N. D.	1.96	1.96	1.98	2.15
Pembina, N. D.	2.06	2.08	2.08	2.25

The Great Northern Railway from Des Lacs, N. D., to Stations in North Dakota:

Miles From Des Lacs		Rate in Dollars and Cents Per Ton of 2,000 Pounds
130	to Buford, N. D.	$1.10
110	to Williston, N. D.	1.06
62	to White Earth, N. D.	.81
12	to Minot, N. D.	.40
141	to Churchs Ferry, N. D.	1.02
158	to Rolla, N. D.	1.22
130	to Devils Lake, N. D	1.10
154	to Lakota, N. D.	1.18
164	to Michigan City, N. D.	1.22
190	to Larimore, N. D.	1.34
266	to Langdon, N. D.	1.67
196	to Arvilla, N. D.	1.38
218	to Grand Forks, N. D.	1.46

Miles From Des Lacs		Rate in Dollars and Cents Per Ton of 2,000 Pounds
258	to Grafton, N. D.	$1.64
224	to Mayville, N. D.	1.46
266	to Casselton, N. D.	1.67
320	to Wahpeton, N. D.	1.78
260	to Ripon, N. D.	1.64
317	to Aneta, N. D.	1.78
257	to Hillsboro, N. D.	1.64
296	to Fargo, N. D.	1.74
124	to Souris, N. D.	1.06
168	to Brockett, N. D.	1.26
306	to Walhalla, N. D.	1.75
273	to Dresden, N. D.	1.67

The Great Northern Railway from Minot, N. D., to Stations in North Dakota:

Miles From Minot		Rate in Dollars and Cents Per Ton of 2,000 Pounds
142	to Buford, N. D.	$1.14
74	to White Earth, N. D.	.86
99	to Bottineau, N. D.	.98
90	to Churchs Ferry, N. D.	.94
137	to Rolla, N. D.	1.14
118	to Devils Lake, N. D.	1.06
142	to Lakota, N. D.	1.14
153	to Michigan City, N. D.	1.18
179	to Larimore, N. D.	1.30
255	to Langdon, N. D.	1.58
206	to Grand Forks, N. D.	1.42
245	to Grafton, N. D.	1.54

Miles From Minot		Rate in Dollars and Cents Per Ton of 2,000 Pounds
277	to Cavalier, N. D.	$1.69
212	to Mayville, N. D.	1.42
254	to Casselton, N. D.	1.58
208	to Wahpeton, N. D.	1.75
227	to Galesburg, N. D.	1.50
248	to Ripon, N. D.	1.58
205	to Aneta, N. D.	1.74
245	to Hillsboro, N. D.	1.54
284	to Fargo, N. D.	1.69
112	to Souris, N. D.	1.02
293	to Walhalla, N. D.	1.71
261	to Dresden, N D.	1.64

Minneapolis, St. Paul & Sault Ste. Marie Railway, and Chicago & Northwestern Railway, joint tariff on Lignite Coal, in carloads, from Bismarck:

To	Rate Per Ton of 2,000 Pounds
Aberdeen, S. D.	$1.46
Redfield, S. D.	1.64
Faulkton, S. D.	1.74

To	Rate Per Ton of 2,000 Pounds
Groton, S. D.	$1.78
Watertown, S. D.	1.83

Minneapolis, St. Paul & Sault Ste. Marie Railway, and Bismarck, Washburn & Great Falls Railway, joint tariffs on Lignite Coal in carloads from Wilton, N. D.:

To	Rate Per Ton	To	Rate Per Ton
Wishek, N. D.	$1.02	Hankinson, N. D.	$1.54
Ashley, N. D.	1.06	Fairmount, N. D.	1.64
Merricourt, N. D	1.18	Elbow Lake, Minn.	1.71
Oakes, N. D.	1.30	Glenwood, Minn.	1.80
Lidgerwood, N. D.	1.50		

Minneapolis, St. Paul and Sault Ste. Marie Railway:

	Rates in Dollars per Ton of 2.000 lbs	
To	From Davis and Burlington, N. D.	From Kenmare N. D.
Portal, N. D.	$ .86	$ .59
Kenmare, N. D.	.68	....
Minot, N. D.	.40	.65
Velva, N. D.	.59	.84
Balfour, N. D.	.68	.93
Harvey, N. D.	.90	1.15
Fessenden, N. D.	.94	1.19
Carrington, N. D.	1.06	1.31
Valley City, N. D.	1.34	1.59
Hankinson, N. D.	1.54	1.79
Lidgerwood, N. D.	1.69	1.94
Oakes, N. D.	1.80	2.05
Boynton, N. D.	1.85	2.10
Wishek, N. D.	1.85	2.10
Braddock, N. D.	1.85	2.10
Ashley N. D.	2.03	2.28
Fairmount, N. D.	1.64	1.89
Elbow Lake, Minn.	1.71	1.96
Glenwood, Minn.	1.80	2.05

Possibility of River Transportation for Lignite.—At first the Missouri river, which flows through the center of the lignite area, with the lignite outcropping in heavy seams along its banks, and enters South Dakota, which is practically without fuel resources, promises to solve the perplexing problem of transportation. A careful study of actual conditions, however, does not place this proposition in an attractive light. The river is closed to navigation during that portion of the year when the coal industry is most active, and during the remainder of the year may be regarded as suitable for the navigation of boats of not more than three hundred tons. The time required for a round trip from Bismarck to Pierre is twelve days, and the daily expense of handling the steamer is considerable. One serious attempt has been made to ship lignite to South Dakota points by boat, but it did not meet with success, due in part to the fact that a number of unique factors in the problem of transportation on the Missouri had not been considered.

THE OPPORTUNITY THAT THE LIGNITE OFFERS FOR DIVERSIFIED INDUSTRIES WITH THE STATE

The desirability of diversifying the industry of a community, so that local markets are created for the various commodities produced, is very manifest. If the farmer, the gardener and the dairyman can find a home market for their produce, due to the presence in the community of a large number of persons who are engaged in manufacturing, both producer and consumer profit by the fact that no charges for transportation are involved in their transactions.

Lignite as Related to Land Interests.—The present and in a much larger measure the future prosperity of the western half of the state depends directly on its wealth of readily available fuel. Railroads are not numerous, and coal brought either from the east or west is very expensive on account of the long haul. Fully nine-tenths of the inhabitants of this part of the state, however, have a lignite bank in operation within fifteen miles of their homes, and a great many of them obtain their fuel on their own premises. This could be done by a much larger number did not the demand made on their time in settling a new country make it more economical to haul fuel a few miles rather than expend the time necessary to open a lignite bank at their own door. Cheap and abundant fuel is an inducement honestly held out to the settlers throughout this great section of the state.

The great significance of the lignite deposits to the question of irrigation is considered in a later chapter. By its use hundreds of thousands of acres of naturally fertile land will yield certain and abundant crops.

The establishment of mills and creameries is greatly favored by the cheapness of lignite, and their presence in every community is a direct benefit to those engaged in agriculture.

Lignite as Related to Manufacturing.—In practically every flouring mill in the state, west of the Red River valley, lignite is used to great advantage. Some of these mills are of large size, having a daily output of from 400 to 500 barrels a day in addition to custom grinding. Every year sees the erection of more mills, the territory in which they are found going farther and farther west as the country is subdued for the growth of cereals.

There is no part of the state where dairying, carried on in connection with stock raising, cannot be carried on to great advantage, and this fact is manifesting itself in the increasing number of creameries that are being erected where a few years ago the stock raising interests were the only ones recognized.

The great quantities of straw that are annually consumed in the stack suggest the possibility of paper board mills and other manufacturing industries which, aided by cheap fuel, can utilize this material. The state consumes a considerable amount of the products manufactured from straw, which, on account of bulk and weight, are not cheaply transported. Foundries and factories to produce the implements used in such numbers by the agricultural interests of the state will be practical when the population increases sufficiently to furnish the necessary labor conditions.

The fact that even the smaller cities and towns of our state enjoy electric light and water works is due directly to the lignite. The benefits and luxuries of advanced civilization are extended very widely over the state by the abundance of cheap fuel.

Association of Lignite With Valuable Clays.—One of the greatest natural endowments of the state is the great deposits of valuable clays which are associated directly with lignite. At a number of points the clays which are stripped from the lignite or taken out incidentally in mining are made into high grade brick, the lignite furnishing the fuel used for all the manufacturing processes. Fire clays which stand the highest tests in ovens and smelters are made into brick which are shipped to St. Paul and Milwaukee on the east, and to Butte, Montana, on the west. This industry is as yet in its infancy, but it promises to expand rapidly.

The desirability of cheap and permanent building material and its importance in the development of the state is not to be over estimated. Nearly all the brick used in the state are now made within its borders and the time will certainly come when North Dakota will become an exporter of high grade facing and fire brick.

Pottery clays are also present in great abundance, but as yet are undeveloped. They deserve the careful consideration of capitalists.

Sandstones which justify extensive development occur in buttes which contain great deposits of lignite, and their availability has been pointed out in the chapter on mineral statistics.

IRRIGATION

There is a widespread interest throughout the country in plans for bringing to its full measure of productiveness the semi-arid tract which extends north and south half way across the continent, east of the Rocky mountains, and of which North Dakota possesses a portion. The average rainfall of the western portion of the state is about eighteen inches, and very often it is distributed during the growing months so as to yield, in connection with the naturally fertile soil, magnificent harvests. Farming conditions, however, are rendered uncertain by a fluctuation in rainfall, and in order to insure crops annually irrigation should be fostered wherever it is practical. President Roosevelt, in his message of December 5, 1901, concisely stated the attitude of the general government toward this question:

"The pioneer settlers on the arid public domain chose their homes along streams from which they could divert the water to reclaim their holdings. Such opportunities are practically gone. There remain, however, vast areas of public land which can be made available for homestead settlement, but only by reservoirs and main-line canals impracticable for private enterprise. These irrigation works should be built up by the national government. The lands reclaimed by them should be reserved by the government for actual settlers, and the cost of construction should, so far as possible, be repaid by the land reclaimed. The distribution of the water, the division of the streams among irrigators, should be left to the settlers themselves, in conformity with the state laws and without interference with those laws or with vested rights. The policy of the national government should be to aid irrigation in the several states and territories in such manner as will enable the people in the local communities to help themselves, as will stimulate needed reforms in the state laws and regulations governing irrigation.

"The necessary foundation has already been laid for the inauguration of the policy just described. It would be unwise to begin by doing too much, for a great deal will doubtless be learned, both as to what can and what cannot be safely attempted, by the early efforts, which must of necessity be partly experimental in character. At the very beginning the government should make clear, beyond shadow of doubt, its intention to pursue this policy on lines of the broadest public interest; but only in accordance with the advice of trained experts, after long investigation has shown the locality where all the conditions combine to make the work most needed and fraught with the greatest usefulness to the community as a whole. There should be no extravagance, and the believers in the need of irrigation will most benefit their cause by seeing to it that it is free from the least taint of excessive or reckless expenditure of the public moneys."

The sentiment voiced by the president found expression in congress in the passage of the "Act for the Reclamation of Arid Lands," one of the most valuable of legislative acts, which was brought to a successful issue in a large measure through the energy of the North Dakota members of congress. The interest of the public in this measure is so general that it is given below in full.

While little of the land of North Dakota is to be classed as arid, portions of the state need an artificial water supply in addition to the rainfall during certain years.

An Act appropriating the receipts from the sale and disposal of public lands in certain states and territories to the construction of irrigation works for the reclamation of arid lands.

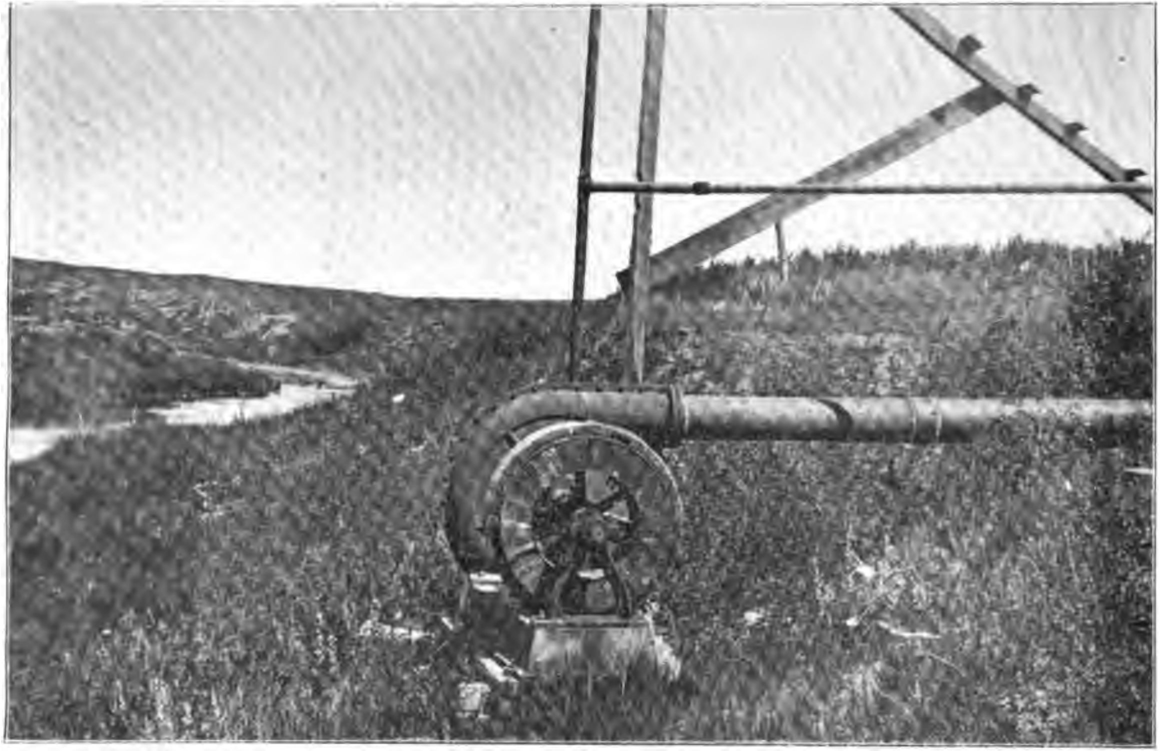
Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled:

SECTION 1. That all moneys received from the sale and disposal of public lands in Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Utah, Washington and Wyoming, beginning with the fiscal year ending June thirtieth, nineteen hundred and one, including the surplus of fees and commissions in excess of allowances to registers and receivers and excepting the five per centum of the proceeds of the sales of the public lands in the above states set aside by law for educational and other purposes, shall be, and the same are hereby, reserved, set aside and appropriated as a special fund in the treasury to be known as the "reclamation fund," to be used in the examination and survey for the construction and maintenance of irrigation works for the storage, diversion and development of waters for the reclamation of arid and semiarid lands in the said states and territories, and for the payment of all other expenditures provided for in this act: Provided, That in case the receipts from the sale and disposal of lands referred to in this section are insufficient to meet the requirements for the support of the agricultural colleges in the several states and territories, under the act of August thirtieth, eighteen hundred and ninety, entitled, "An act to apply a portion of the proceeds of the public lands to the more complete endowment and support of the colleges for the benefit of agriculture and mechanic arts, established under the provision of an act of congress approved July second, eighteen hundred and sixty-two," the deficiency, if any, in the sum necessary for the support of the said colleges shall be provided for from any money in the treasury not otherwise appropriated.

SEC. 2. That the Secretary of the Interior is hereby authorized and directed to make examinations and surveys for, and to locate and construct, as herein provided, irrigation works for storage, diversion and development of waters, including artesian wells, and to report to congress at the beginning of each regular session as to the results of such examinations and surveys, giving estimates of cost of all contemplated works, the quantity and location of the lands which can be irrigated therefrom, and all facts relative to the practicability of each irrigation project; also the cost of works in process of construction as well as those which have been completed.

SEC. 3. That the Secretary of the Interior shall before giving the public notice provided for in section 4 of this act withdraw from public entry the lands required for any irrigation works contemplated under the provisions of this act, and shall restore to the public entry any of the lands so withdrawn when, in his judgment, such lands are not required for the purposes of this act; and the secretary of the interior is hereby authorized, at or immediately prior to the time of beginning the surveys for any contemplated irrigation works, to withdraw from the entry, except under homestead laws, any public lands believed to be susceptible of irrigation from said works; Provided, That all lands entered and entries made under the homestead laws within areas so withdrawn during such withdrawal shall be subject to all the provisions, limitations, charges, terms and conditions of this act; that said survey shall be prosecuted diligently to completion, and upon the completion thereof, and of the necessary maps, plans and estimates of cost, the Secretary of the Interior shall determine whether or not said project is practicable and advisable, and if determined to be impracticable or unadvisable, he shall thereupon restore said lands to entry; that public lands which it is proposed to irrigate by means of any contemplated works shall be subject to entry only under the provisions of the homestead laws, in tracts of not less than forty nor more than one hundred and sixty acres, and shall be subject to the limitations, charges, terms and conditions herein provided; Provided, That the commutation provisions of the homestead laws shall not apply to entries made under this act.

SEC. 4. That upon the determination of the Secretary of the Interior that any irrigation project is practicable, he may cause to be let contracts for the construction of the same, in such portions or sections as it may be practicable to construct and complete as parts of the whole project, providing the necessary funds for such portions or sections are available in the reclamation fund, and thereupon he shall give public notice of the lands irrigable under such project and limit of area per entry, which limit shall represent the acreage which, in the opinion of the Secretary, may be reasonably required for the support of a family upon the lands in question; also of the charges which shall be made per acre upon the said entries, and upon lands in private ownership which may be irrigated by the waters of the said irrigation project, and the number of annual installments, not exceeding ten, in which such charges shall be paid and the time when such payments shall commence. The said charges shall be determined with a view of returning to the reclamation fund the estimated cost of construction of the project, and shall be apportioned equitably; Provided, That in all construction



A Rotary Pump on Green River, Used in Irrigation.

UNIV. OF MICH.

work eight hours shall constitute a day's work, and no Mongolian labor shall be employed thereon.

SEC. 5. That the entryman upon lands to be irrigated by such works shall in addition to compliance with homestead laws, reclaim at least one-half of the total irrigable area of his entry for agricultural purposes, and before receiving patent for the lands covered by his entry shall pay to the government the charges apportioned against such tract, as provided in section four. No right to the use of water for land in private ownership shall be sold for a tract exceeding one hundred and sixty acres to any one land owner, and no such sale shall be made to any land owner unless he is an actual bona fide resident of such land, or occupant thereof residing in the neighborhood of said land, and no such right shall permanently attach until all payments thereof are made. The annual installments shall be paid to the receiver of the local land office of the district in which the land is situated, and a failure to make any two payments when due shall render the entry subject to cancellation, with the forfeiture of all rights under this act, as well as of any moneys already paid thereon. All moneys received from above sources shall be paid into the reclamation fund. Registers and receivers shall be allowed the usual commissions on all moneys paid for lands entered under this act.

SEC. 6. That the Secretary of the Interior is hereby authorized and directed to use the reclamation fund for the operation and maintenance of all reservoirs and irrigation works constructed under the provisions of this act; Provided, That when the payments required by this act are made for the major portion of the lands irrigated from the waters of any of the works herein provided for, then the management and operation of such irrigation works shall pass to the owners of the lands irrigated thereby, to be maintained at their expense under such form of organization and under such rules and regulations as may be acceptable to the secretary of the interior; Provided, That the title and the management and operation of the reservoirs and the whole works necessary for their operation and protection shall remain in the government until otherwise provided by congress.

SEC. 7. That where in carrying out this act it becomes necessary to acquire any right or property, the secretary of the interior is hereby authorized to acquire the same for the United States by purchase or by condemnation under judicial process, and to pay from the reclamation fund the sums which may be needed for the purpose, and it shall be the duty of the attorney general of the United States upon every application of the Secretary of the Interior, under this act, to cause proceedings to be commenced for condemnation with thirty days from the receipt of the application at the department of justice.

SEC. 8. That nothing in this act shall be construed as affecting or intending to affect or in any way interfere with the laws of any state or territory relating to the control, appropriation, use or distribution of water used in irrigation, or in any vested right acquired thereunder, and the Secretary of the Interior, in carrying out the provision of this act shall proceed in conformity with such laws, and nothing herein shall in any way affect any right of any state or of the federal government of any land owner, appropriator or user of water in, to or from any interstate stream or the waters thereof; Provided, That the right to the use of the water acquired under the provisions of this act shall be appurtenant to the land irrigated, and the beneficial use shall be the basis, the measure and the limit of the right.

SEC. 9. That it is hereby declared to be the duty of the Secretary of the Interior in carrying out the provisions of this act, so far as the same may be practicable and subject to the existence of feasible irrigation projects, to expend the major portion of the funds arising from the sale of public lands within each state or territory hereinbefore named for the benefit of arid and semiarid lands within the limits of such states or territory; Provided, That the Secretary may temporarily use such portion of said funds for the benefit of arid or semiarid lands in any particular state or territory hereinbefore named as he may deem advisable, but when so used the excess shall be restored to the fund as soon as practicable, to the end that ultimately, and in any event, within each ten-year period after the passage of this act, the expenditures for the benefit of said states and territories shall be equalized according to the proportions and subject to the conditions as to practicability and feasibility aforesaid.

SEC. 10. That the Secretary of the Interior is hereby authorized to perform any and all acts and to make such rules and regulations as may be necessary and proper for the purpose of carrying the provisions of this act into full force and effect.

Approved June 17, 1902.

By the provision of this act North Dakota is favored in a larger measure, perhaps, than any other state.

A study of the possibilities that the state presents for irrigation has already been begun, the State Geological Survey and the Soil Survey of the Agricultural College co-operating with the Department of Hydrography of the United States Geological Survey. This study must be carried to completion before definite propositions for irrigation can be considered The streams are to be gauged, and their ability to furnish water at various points in their course during those months when the water is needed, or is wanted for storage purposes. Reservoir sites are to be determined, their cost estimated and the area that can be irrigated from them carefully computed.

A special study in connection with irrigation rises out of the abundance of lignite in the semiarid region. The three points that must be considered in connection with irrigation are: The water supply; means for securing the head necessary to distribute water over large tracts of land, and the surface of the land, which must admit of a uniform distribution of water. An abundance of water is always present in the Missouri river, and during the months when it is most needed, in the lower courses of its larger tributaries. In their upper courses and along the minor tributaries of the Missouri temporary dams which would hold large quantities of water can be constructed at small expense, which will act as storage reservoirs, carrying into the summer the water from the more abundant flow earlier in the year. In these ways a supply of water can be secured which will be sufficient to irrigate large tracts of land in the western part of the state. Large reservoir sites are probably practical at some points, but it is certain that much of the land which it is desirable to irrigate cannot be provided with water from a large central distributing basin, on account of topographic and drainage conditions. Much of the land that is level enough to irrigate is in the form of broad terraces, which border the streams. About Yule, on the Little Missouri, these terraces are three in number, twenty-five, 100 and 120 feet above the water.

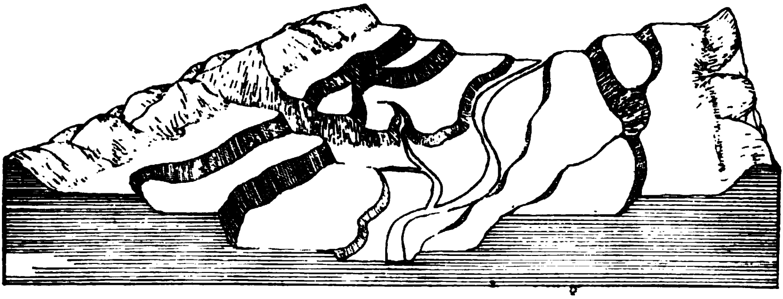


Fig. 13. Diagram illustrating terraces on the Little Missouri.

Between Bismarck and the mouth of Apple creek there are two broad terraces twenty and fifty feet above the Missouri, the city of Bismarck standing on the eastern edge of the higher terrace. The meandering of the streams often cuts these terraces into detached fragments which occur first on one bank and then on the other. Often, however, 1,000 acres or more in a single terrace remain intact, and with a slightly sloping surface and good soil invite cultivation. The total acreage along the Missouri and its tributaries in this form is very considerable. Back of these terraces there are many large tracts suitable for irrigation if water from the river can be elevated seventy-five or 100 feet.

It will not be economical to construct dams that will raise the water sufficiently to irrigate these isolated tracts. Some of them can be watered from reservoirs constructed in draws which extend back from the river. Only a detailed study of topographic conditions will determine the extent to which irrigation by such reservoirs can be carried, but during the past summer a number of points that will justify careful measurements were noted.

A method which admits of a much wider application is found in pumping water from the stream up to the flats. Where fuel is cheap such a method is wholly practical. In California pumping for irrigation purposes is practiced to a considerable extent, the fuels used being oil and wood.*

Several extensive plants for irrigation purposes have been erected in the west.

"In Arizona is a high-pressure pumping engine capable of irrigating 100 acres per season which cost when erected $1,000, or $10 per acre irrigated, while the cost of running is but $5 per acre. A larger and more modern plant operated near Tuscon consist of two compound Smith-Vaile pumping engines, capable, it is claimed, of irrigating 600 acres per season, at a cost for operation of $3 per day, the first cost for this plant laid down having been $4,200, and the height of lift being seventy feet. Still another pumping plant, consisting of an automatic cut-off condensing engine with two 150-horse power boilers, has been erected on the Yuma river. The pumping engine has eighteen-inch stroke and forty-two-inch cylinders, and is of 165-horse power capacity. This is an Allis pumping engine, having a fly wheel weighing seven tons and making sixty-seven revolutions per minute, the capacity of the pump being twelve second-feet, or about twenty-four acre-feet in a day of twenty-four hours.

"This pump delivers water through a twenty-six-inch redwood stave main, elevating the water eighty feet, and this is stored in a reservoir having twenty-five acre-feet capacity. A year's test of this engine, according to the claims of the owner, shows it to be capable of discharging twelve second-feet at a cost of $3 per second-foot for fuel.

"There has recently been erected at Eureka, Kansas, a pumping plant for the irrigation of about 3,000 acres. This consists of two horizontal return tubular boilers and two compound, duplex, direct-acting steam pumping engines of a maximum capacity of 530,000 cubic feet or about twelve acre-feet per day of twenty-four hours, equivalent to six second-feet, with a total lift of sixty-five feet. The cost of this plant, exclusive of the storage reservoir, was about $8,000, while the cost for operation is estimated to be $1.60 per acre, assuming that the full area is covered."

CENTRIFUGAL AND ROTARY PUMPS

"For lifting large volumes of water to moderate heights, the centrifugal pump is the most economical and efficient, as well as simplest in construc-

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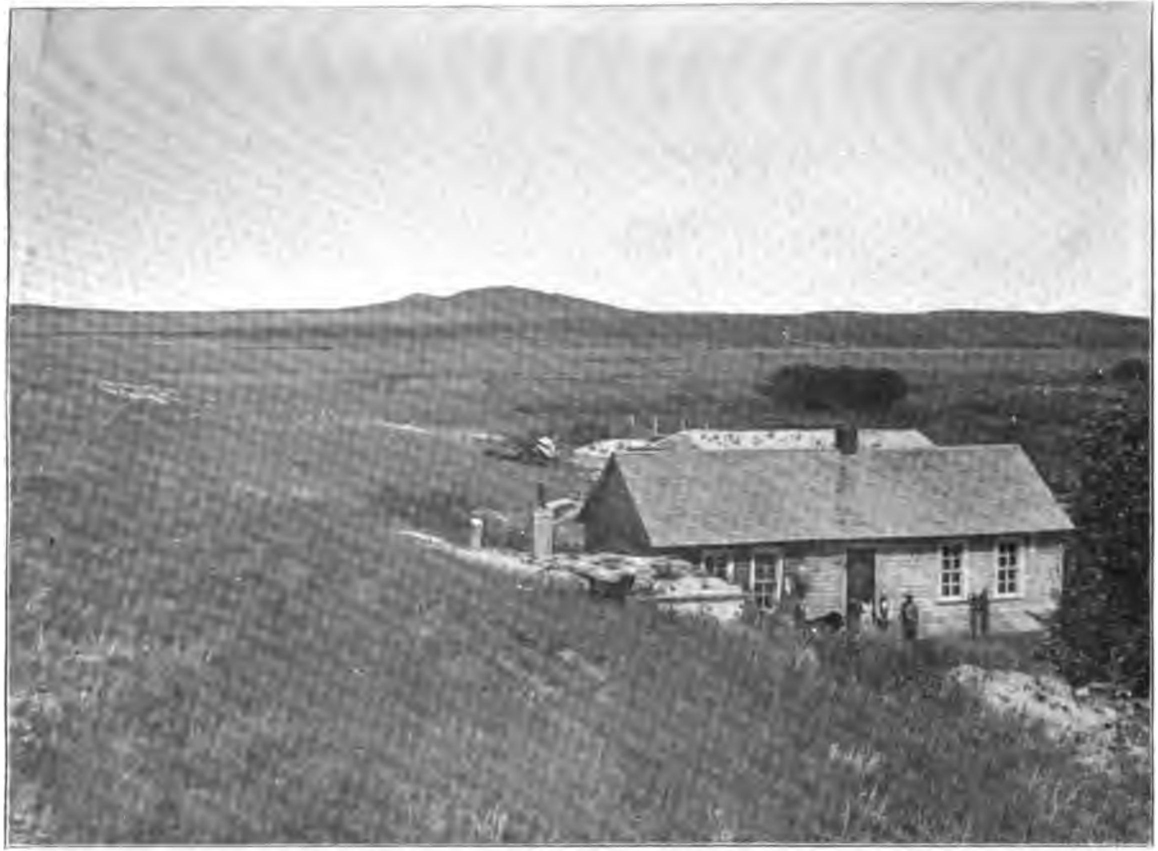
* Twelfth Census of the United States; Agriculture, Part II, p. 831.



The Valley of Green River, Illustrating a Common Type of Topography in the Lignite Area, and a Valley of a Small Stream, Capable of Irrigation.

tion and cheapest in first cost of plant and erection. It is not, however, so substantial as a direct-acting steam pumping engine and therefore is not so suitable for large permanent works requiring considerable lifts. Where circumstances are suited to its employment, it is one of the best pumps for irrigation. It is adapted to raising water heavily charged with sediment. In construction a centrifugal pump is similar to an outward-flow turbine driven in the reverse direction. Such a pump cannot be put in action until it is filled with water, an operation which is effected through an opening in its outer casing when the pump is below water, or by means of a steam jet when the pump is above water. The efficiency of a centrifugal pump diminishes with the lift, and for lifts exceeding twenty-five or thirty feet a force or plunger-pump produces better results. Centrifugal pumps are generally driven by water, steam or gasoline motors, with which they are connected by belting or shaft and gearing, and they may be erected independently of the motors and at some distance from them. They are also made to gear directly on the motor shaft.

"Many forms of centrifugal pumps are now on the market. They are of varying capacities, from those having two-inch discharge pipes up to those having twenty-four-inch discharge pipes, the largest size being capable of elevating as much as fifteen second-feet, or the same number of acre-feet in a day of twelve hours. Such pumps as these vary in cost according to circumstances, but the larger sizes cost for plant about $100 per second-foot of capacity for moderate lifts, while for fifteen second-foot pumps they require engines capable of developing about five horse power per foot of lift.

"Among the most notable centrifugal pumping plants for irrigation is one for the Vermilion Canal company in Louisiana, consisting of six fifteen-inch pumps, which are claimed to be capable of discharging 130 second-feet of water against a head of twenty feet, and are operated by two engines, each of 250 horse power. Another centrifugal pump working on a farm in southern Arizona and operated by a ten-horse power engine and boiler, has a capacity of two-thirds of a second foot. The operation of this plant calls for the consumption of about one cord of wood per day of twenty-four hours, and is capable of irrigating about three acres per season. A similar pump in the same locality and operated by a gasoline engine of thirty-five horse power will handle about eleven one-half acre-feet in twenty-four hours on a consumption of about ninety-four gallons of gasoline, other centrifugal pumps of small capacity for watering five to ten acres per day and in the course of an irrigation season from fifty to 100 acres, are operated by one man at a cost of about $2.50 per acre irrigated for maintenance and $15 per acre for cost of plant.

"It is proposed to erect an extensive centrifugal pumping plant for the Summit Lake Water company in California, and the estimates of the engineer for a plant capable of irrigating 40,000 acres, including distributing canals and other items, is $81,000, the cost of the pumping plant alone being estimated at about 75 cents per acre, while the cost for operation of and interest on the pumping plant during an irrigation season is estimated to be about $1 per acre, on the assumption that the depth of irrigation will be one foot and the lift twenty feet. The figures are considerably below those of most gravity systems."*

An interesting description of irrigation by pumping is given by Chandler in his report on water storage on Cache creek, California.**

Conditions here described coincide so nicely with those existing near the headwaters of the tributaries of the Missouri in North Dakota that a portion of the report is reproduced.

> "Not being able to rely upon irrigation ditches, many of the farmers about Woodland have resorted to pumping from Cache creek and from wells. Now that their pumping plants are established, most of the operators find them so effective that they would hesitate to abandon them for even an improved system of ditches. * * * In the Woodland district there are not fewer than twenty places where pumps are now used. Eight of these depend on Cache creek for their supply. As the pumping plants are all below Moore's dam, the supply is generally insufficient after the middle of July. When visited in the latter part of July, 1900, the pumps on the creek could be used only half a day at a time. There was no water flowing in the creek, but long pools have been formed where the water, percolating through the gravel, was forced to the surface. It was from depressions in the pools that the pumping was done, and when the supply was exhausted the pumps were stopped until the pools filled again. In some places earthen dams one foot or two feet high were thrown across the bed to hold the water, and small ditches were dug between the pools above to let more water down. * * * With the exception of the gasoline engine of Mr. S. V. Scarlet, all of the engines in use are steam engines. Straw, brush, wood and coal are used for fuel. The average price paid is 75 cents per load for straw, $4 a cord for wood, $8.50 a ton for coal, and 11 cents per gallon for gasoline."

Throughout the western part of North Dakota the lignite furnishes a cheap and available fuel for irrigation purposes.

The possibility of this plan has already been grasped by farmers at two or three points in the state. Fisher Brothers, on Green river, a small tributary of the Heart, seven miles north of Dickinson, have irrigated for two years, pumping water from the river. The lift is fifteen feet, and a centrifugal pump with a discharge pipe having an inside diameter of eight inches is used. A temporary dam ten inches high and thirty feet long was thrown across the river in 1901 and retained all the water needed to irrigate forty acres. In 1902 an abundance of rain made irrigation unnecessary. With this pump, which is driven by an ordinary farm engine, 1,500 gallons per minute are easily raised fifteen feet. The cost of the pump delivered was $250. Mr. Fisher estimates that even in a dry season he would have no difficulty in irrigating 200 acres with his present equipment. Two dollars' worth of coal was burned per day, coal costing 50 cents per ton at a neighboring bank. Plate XXXIII illustrates Fisher's centrifugal pump and the Green river from which water is taken. Plate XXXIV shows the Green river valley, which is a type of the valleys of small streams in the lignite area that may easily be irrigated.

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* Water Supply and Irrigation Papers, No. 1, p. 48 and 50.

** Water Supply and Irrigation Papers, No. 45, p. 23.

Mr. A. F. Riley, on the Little Heart river, near Gladstone, last year irrigated twenty acres by means of a dam thrown across a draw. Next year he proposes to irrigate sixty acres by means of a centrifugal pump. Lignite occurs on his farm outcropping in a four-foot seam, and can be had for the mere labor of mining.

Hundreds of localities are as favorably situated as these, and as the population in the western part of the state increases, irrigation will become common.

During the summer of 1903 in co-operation with the Department of Hydrography of the United States Geoleogical Survey, the State Survey proposes to put in the field two parties to follow all of the streams in the lignite area, determine more exactly the outcrops of coal, the extent of land subject to irrigation and the lift necessary to bring the water to them from the streams. When this work is completed an extended report will be made.

Away from the streams wells will very often furnish water for irrigation on a large scale. If a vertical shaft is sunk even to moderate depths coal will commonly be found, but it is attended by so much water that without proper pumping facilities mining is impossible. With a simple surface reservoir into which to pump the water that accumulates in the pit, it may be possible to secure an abundance of water and of coal from the same shaft.

WATER RESOURSES OF THE DEVILS LAKE REGION

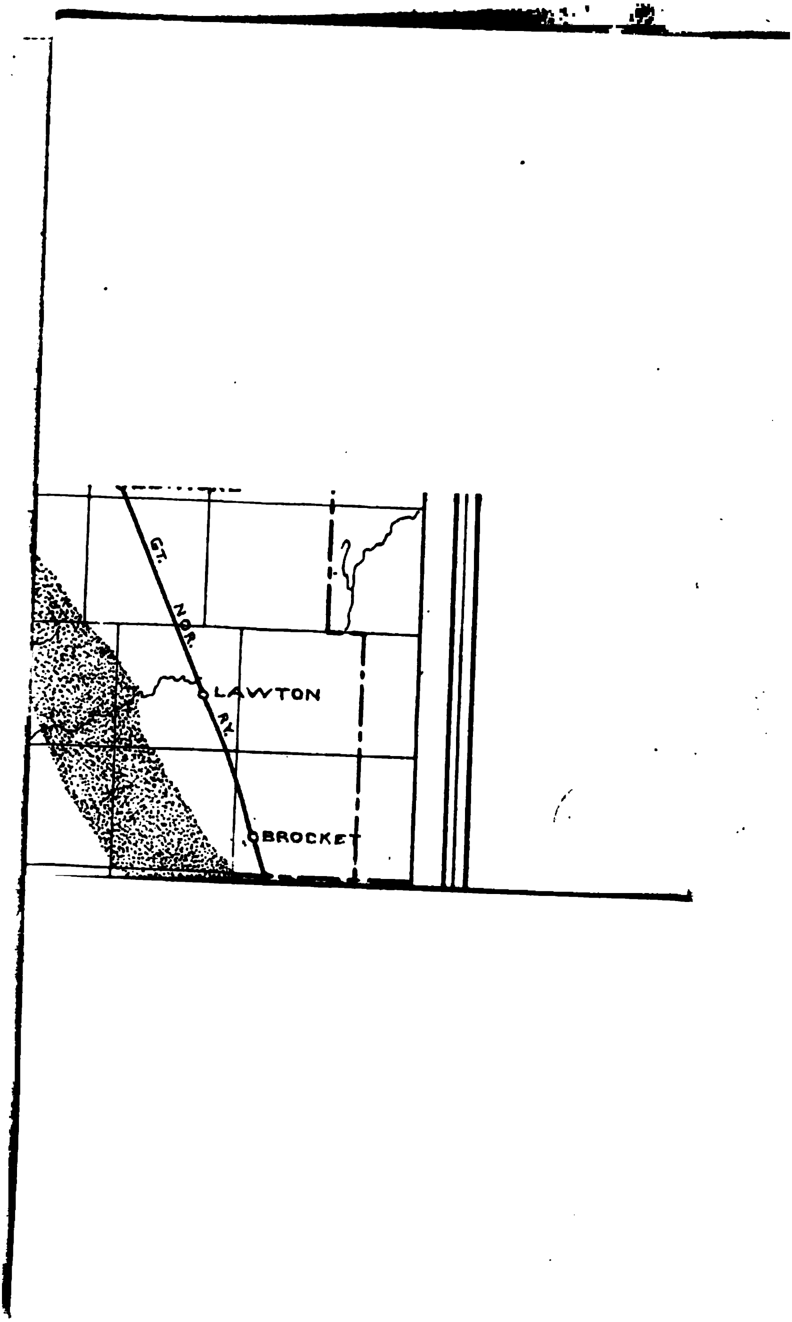
E. J. BABCOCK

INTRODUCTION

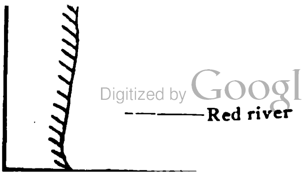
The results of work embodied in this paper deal with the surface and shallow water supplies of that large and interesting portion of North Dakota known as the Devils lake drainage basin. While these investigations are somewhat preliminary in nature, it is hoped that the information given will be of direct economic value as well as of geologic interest. Special attention is given to the possible application of large quantities of water obtainable from the shallow well reservoirs of this region, and also to the improvement of the sanitary conditions of water used for domestic purposes. The origin, distribution and character of soils, and the best method of tillage, the securing and using of water irrigation and many other similar questions all involved the consideration of geological facts. All underground water supplies depend largely for their sources, quality, character and permanency upon the surrounding topography and geological features. The essential conditions for a wholesome water supply for domestic use, upon which depends the health of the community, are very largely determined by geological agencies and structures. To ascertain the quantity and purity of a water supply it is not only necessary to consider the amount of rainfall and the extent of the gathering area, but it is even more important to know the nature of the underlying rocks, for this is sure to have a great influence upon the yield and character of the water. Considerable space in this report has therefore been given to the general topographic and geological conditions.

TOPOGRAPHY

The Devils Lake Basin.—The area at present occupied by Devils lake and the smaller adjoining lakes comprises but a small fraction of what may be called the Devils lake drainage



occasionally interrupted by low lands, until it practically unites with the Turtle mountain highland west of the Pembina mountains. Topographically as well as geologically these



small fraction of what may be called the Devils lake drainage basin. As shown by the map, this district extends from the Turtle mountains on the north to a series of prominent morainic hills lying between Devils lake and Stump lake on Sheyenne river on the south, and from a few miles north of Stump lake on the east to a point near the western boundary of Pierce county.

Looking toward the south from the heights of the Turtle mountains, one has spread out 400 feet or more below him a beautiful view of a gently rolling prairie region, dotted with small farm houses surrounded occasionally by planted groves. This undulating surface extends as far as the eye can reach, gradually decreasing in elevation as it approaches Devils lake. From points farther east, toward the Pembina mountains, a similar though less rapid descent toward the south is noticeable.

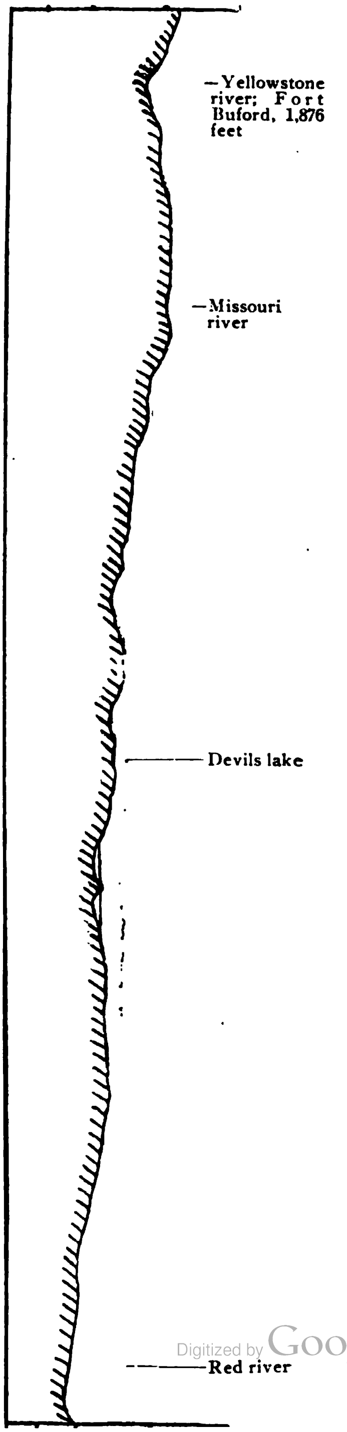


Fig. 14. Profile of North Dakota near the 48th parallel.

About thirty miles west of the Red River of the North, near the international boundary, is an area rising abruptly from the general level of the valley to a height from 400 to 600 feet above the Red river. This elevated land stretches many miles northward into Canada and westward forms a gradually descending plain toward the central part of the state. The northeastern portion of this tract is known as the Pembina mountains. Toward the west it increases slightly in elevation though occasionally interrupted by low lands, until it practically unites with the Turtle mountain highland west of the Pembina mountains. Topographically as well as geologically these two elevations should be considered together. Along the northern part of the eastern slope of the Pembina mountains the tract presents the appearance of a prominent wooded bluff rising 250 to 350 feet above the surrounding level and extending in a nearly direct line toward the south. This ridge gradually decreases in elevation until at its southern extremity it is scarcely more than fifty feet above the country round, and then it is lost in the rolling prairie. Along the eastern edge of the escarpment its elevation above the sea ranges from about 1,100 feet in the eastern part to 1,500 or 1,600 in the northwestern. Beyond the ravines of the streams along the eastern edge, the crest of the Pembina mountains forms a treeless, rolling plateau stretching away toward the west. Over most of this tract between the Pembina and Turtle mountains, a distance of about 100 miles, there is very little to note, except that it is a high prairie. There are but few streams and lakes or other marked surface features. On the eastern and western extremities good crops of small grains are usually raised. The central portion has heretofore been used for grazing, but is now rapidly developing into a wheat growing region. This section is well supplied with a variety of excellent prairie grasses. Eastward this belt ascends gradually toward the Turtle mountains and descends slightly toward the south. The southern slope shows a very gentle drainage system, beginning near the base of the Turtle mountains, and becoming more prominent as it extends further into the Devils lake basin. In fact this basin is the natural drainage reservoir for the waters of a large portion of the eastern part of the northern high land just described. No streams worthy of mention rise along the western part of the district, except those like the Pembina river, which have their sources on the northern side of the Turtle mountains in Canada. The southern surface is, nevertheless, well drained, and without doubt much water slowly percolates through the drift to the underlying Cretaceous clay. The direction of the surface drainage is toward the basin in which Devils lake is situated.

The Turtle mountains proper form a high, rolling plateau about forty miles long and thirty miles wide, its long axis being east and west. The surface rises gradually from all sides, but within one or two miles of the summit the slopes suddenly grow steeper until an elevation from 300 to 400 feet above the surrounding country is attained. The sides of the hills have but little timber, but among the hill tops there are many small trees. The Turtle mountains present a very broken outline on account of the large number of subordinate hills and ridges of which they are made up. The highest of these buttes reaches an elevation of about 2,500 feet above the sea, or about 600 feet above the surrounding country. The top of the mountains has a beautiful rolling surface, covered with trees and dotted with lakes and ponds. Many fine farms are located here. Near the central part of these hills is the attractive little lake Metigoshe.

Springs and spring brooks are common along the hillsides. North of Dunseith and also north of Bottineau are several very large springs. About two miles north of Bottineau a tract of several acres along the hillside seems to consist of one vast spring; and located as this spring is, 300 feet or more above the town, it seems wonderfully well situated to furnish a water supply for domestic purposes and power. The water which oozes out of this hillside is rather highly charged with lime, but otherwise seems to be of excellent character.

The Turtle mountains consist of a mass of Cretaceous clays which have escaped erosion and are covered with a thin layer of drift. This drift has, however, been somewhat cut out on the top of the plateau, and there is thus formed a great gathering reservoir. No doubt a large amount of the water flowing in the brooks and from the numerous springs has seeped through the clays and sand from this high land reservoir.

Measurements along the Great Northern railway give the following elevations in passing toward the northwest:

Locality	Feet Above Sea Level
Grand Harbor	1,461
Churchs Ferry	1,460
Cando	1,490
Bisbee	1,605
Perth	1,736
Rolla	1,823
St. John	1,950

This high land forms an important part of the gathering ground for the water of the Devils lake basin, which is drained, however, only by very small streams, flowing for the most part in coulees which often become quite dry in summer. These coulees enter the lake from various directions, but chiefly from the north. They vary in size from wide depressions, only two or three feet deep, to narrow channels fifty to 100 feet wide, and with banks twenty-five or fifty feet high. When water is not flowing through them, small ponds are frequently left; and when entirely drained, such coulees, especially the wider, shallow ones, usually make fine hay and pasture lands. At one time these coulees were doubtless important factors in supplying water to Devils lake. This is particularly true of Mauvaise coulee, which has its source very near the international boundary and flows through Lake Irvine into Devils lake. Although its shallow channel may now be dry in its northern portion, it was probably the outlet for a short period during the melting of the ice sheet for the flooded district along the southeastern base of Turtle mountains, and it seems to have carried a large amount of water.

One of the most noticeable features of the district is a series of low, rounded hills, which stretch from the northwest toward the southeast and give the whole surface a very undulating appearance. North of the lake these hills, all of which are probably of morainic origin, are not so wide or high as those to the south. Along the southeastern end of Stump lake these morainic swells have a thickness of from fifteen to sixty feet, as shown by wells which pass through the drift and enter the Cretaceous shales. Along the southern shore of Stump lake is a group of hills rising from 150 to 200 feet above the lake level, which are at least covered with morainic deposits. These hills descend gradually toward the south until they reach the Sheyenne valley, which is cut down 100 feet or more below the surface. Along this whole distance boulders are rather thickly scattered, and sand and gravel ridges are not uncommon. This series of morainic ridges is well developed all along the tract south of Fort Totten, through the Indian reservation, and southwest to Minnewaukan. South of Minnewaukan the ridges widen out into a high, rolling country which extends three or four miles south of Oberon, while still farther to the southwest, along the Minneapolis, St. Paul & Sault Ste. Marie railway, they pass into the rich and gently undulating prairie which is drained by the upper branches of the Sheyenne and James rivers.

Most of the hills along the southwestern shore of Devils lake and between the lake and Oberon rise from seventy to 100 feet above the lake level. Sully's Hill and other hills about Fort Totten are about 225 to 250 feet above the lake.

Fig. 15. Morainic hills west of Devils lake.

That this great morainic deposit rests immediately upon Pierre shale is evident from the shale exposures found in the occasional deep cuts and artificial excavations made among the hills. The whole district, however, is thickly covered with drift material, even the highest points being often covered with rock fragments from the size of gravel to boulders several feet in diameter. These fragments are generally of granite or gneiss, but are frequently mixed with a large proportion of light gray limestone, probably from the Silurian. All of this material was doubtless transported from Canada by the ice. This morainic ridge passes near Minnewaukan and thence to the northwest, crossing the Great Northern railway near Knox and Pleasant lake, where it unites with another very marked morainic ridge, from one-half mile to two miles wide, running a few miles southwest of Churchs Ferry in a winding course east to Grand Harbor, where it bends quickly to the north around the southern end of Dry lake, from which point it extends for miles to the east.

Lying between the last two series of ridges, immediately west of Devils lake and north of Minnewaukan and between that point and the Mauvaise coulee, is a low, sandy tract which stretches toward the northwest as far as Knox, and is drained by several shallow coulees. Low sand ridges are seen extending to the north. This is very clearly an old beach of Devils lake, and indicates that the water stretched out many miles beyond its present limits.

Going west of Oberon, one passes gradually from the morainic belt south of Devils lake to a somewhat lower, rolling prairie, known as Antelope valley, which is bordered on the north by morainic hills and on the south by a slight elevation approaching the Sheyenne river. This fertile undulating valley extends northwestward to the vicinity of Girard lake, to the border of what was probably, during a portion of the glacial period, a large lake extending from this point west to Minot and around Turtle mountains, thirty or forty miles into Canada. This has been called Glacial Lake Souris. During a part of its history this lake appears to have been drained by numerous outlets to the south, the most important of which developed into the Sheyenne and James rivers. When the waters were high, they probably filled the Sheyenne valley and eroded at successive stages the terraced banks so noticeable along the upper courses of this stream. At the same time doubtless many of the coulees which pass through Antelope valley and into the Sheyenne river were formed and were then swollen streams, aiding in the drainage of the area bordering Glacial Lake Souris. At present only a few small lakes, like Girard and Buffalo, show the source of the Sheyenne and James rivers. The high banks, the shore marks, the high washed boulders and stumps of petrified trees, and the deposits, afford unmistakeable evidence that Girard lake was at one time a large, deep body of water, occupying an area several times as great as that which it now covers. This old lake had a very irregular outline, and its length was probably greatest from northwest to southeast. In fact, it is not impossible that it may have extended ten or twelve miles south of Rugby, or even have connected with Lake Souris. The lake is now about three miles long and from one to two miles wide.

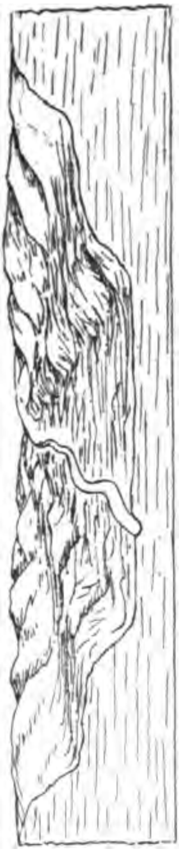


Fig. 16. Valley of the Sheyenne river, showing terraces.

The central portion of the state south of Devils lake is drained by the Sheyenne and James rivers. The Sheyenne rises about thirty miles west of Devils lake, and flows in a very winding channel for about ninety miles toward the east; then it takes a course nearly due south for about 100 miles, until twenty miles or so from the southeastern limit of the state, it turns northeasterly into the Red river valley, and debouches into the Red river a short distance above Fargo. For the greater part of its course the stream is narrow, its channel being cut through yellow and blue clays. Often the banks are strewn high upon the sides with glacial debris. They vary greatly in height, from a few feet near the mouth to eighty or ninety feet near the upper waters. Along parts of the river course are well marked terraces, which may have been formed while the stream was an outlet for the glacial lake region to the north. The western part of the country drained by the Sheyenne river is a high rolling prairie, often from 1,300 to 1,600 feet above the sea. The soil is very rich, and when there is a fair amount of rainfall produces an abundant crop.

Some of the small streams which form the headwaters of the James river are southwest of Devils lake and within a few miles of the source of the Sheyenne. At this place the two rivers are separated by a ridge several miles wide. The country around the western tributaries of this river is of the same character as that about the Sheyenne. The James river flows for about 150 miles in a southeasterly direction until it crosses the state line into South Dakota. The general character of the stream and the surrounding country is much the same as that of the Sheyenne river. The surface to the south is rather more level and much lower in altitude. The channel is cut through clay and drift, but the soil and subsoil have a larger proportion of sand than is found farther north.

STRATIGRAPHY

The rather uniformly level character of the surface and the absence of uplifts and very deep valleys render difficult a study of the underlying strata throughout the state. Outcrops of the deeper rocks are few, and most of the available information concerning not only the lower formations but also portions of the upper beds has been obtained from a study of deep well borings.

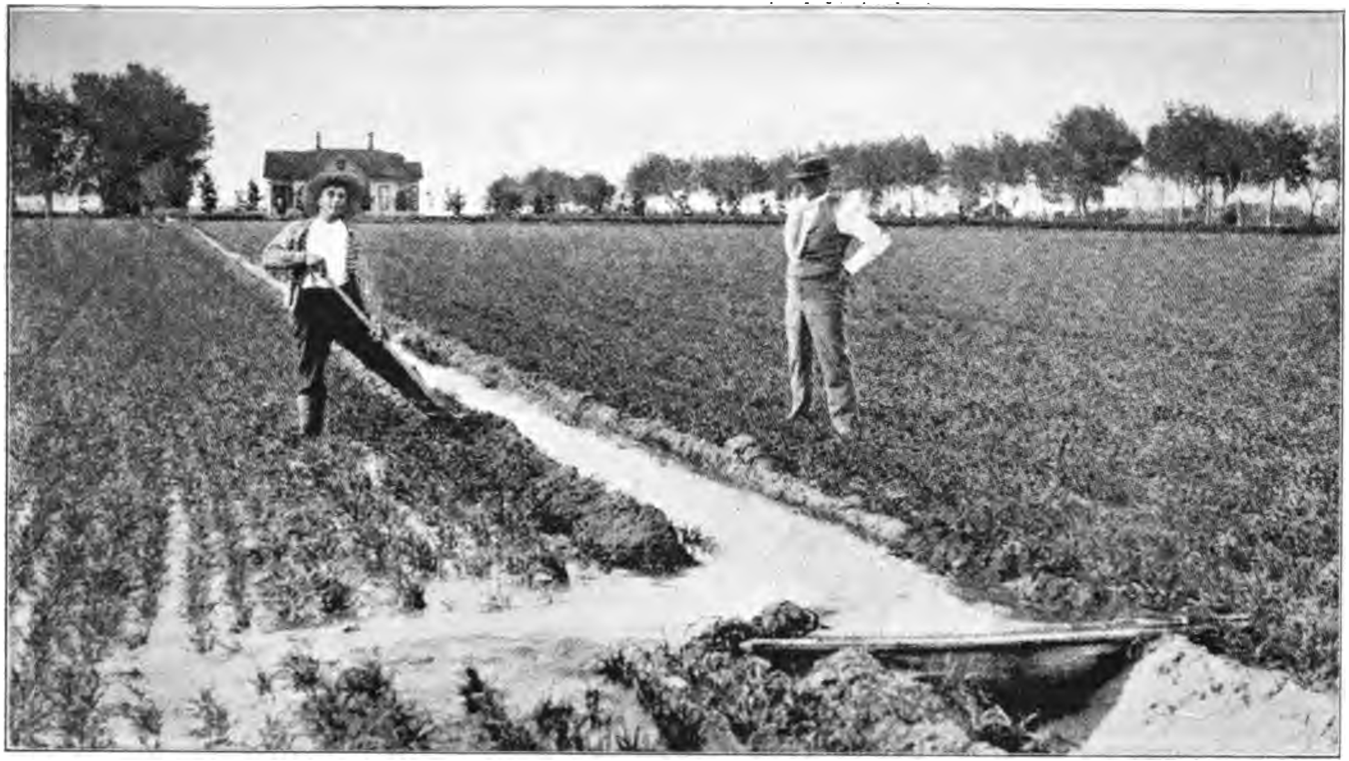
The formations occurring in the state, though only the later ones appear on the surface, include rocks of the Archean, Cambrian, Silurian, Cretaceous (Dakota, Benton, Niobrara, Pierre and Laramie), as well as glacial drift and alluvial deposits. No effort has been made to differentiate the Algonkian from the Archean. The Cretaceous rests upon the older rocks and extends over the western part of the state, its thickness ranging from a few feet to 1,500 or more. The various beds of this age are by far the most characteristic and important in the state. The Laramie is found in the western part of the state, chiefly beyond the Missouri river, and is characterized by extensive beds of lignite and valuable deposits of fire clay and potter's clay.

In this discussion only a brief description will be given of the geological formations which are of particular significance to the water supply in this region. The rocks of the Archean have been reached by a great number of deep well borings in the eastern portion of the state, and the Red river valley is doubtless underlain by an extension of the great Archean belt found in northern Minnesota and southern Canada. Here, as elsewhere, granite, gneiss and schists are the characteristic rocks.

Archean.—Near Big Stone lake are outcrops of granite, and northeast of this point it has been found in wells, beneath from fifty to 125 feet of till. In some places, at least, magnesian limestone overlies the granite. A well in Moorhead reaches granite at a depth of about 365 feet, under a covering of sand, blue shale and glacial and alluvial debris. At Grand Forks, eighty miles farther north, granite or gneiss was reached at 385 feet, being overlain by a thick layer of Silurian limestone and beds of gravel, sand and clay. Immediately above the granite or gneiss was a deposit of granitic sand and gravel. The final borings, which were taken some fifteen feet in the solid rock, showed a predominating pink feldspar and a composition characteristic of light gneiss or granite.

At Grafton, about forty-five miles farther north, Archean rock was reached at 903 feet, and still farther north, across the boundary it was found near the mouth of the Red river and to the northwest of Lake Winnipeg. How deeply it is covered to the west of the Red river valley cannot be told. The old Archean floor, on which lie the deposits in the Red river valley westward, was evidently rolling and possibly eroded, as indicated by the deposition of the superincumbent sand and gravel found in some well borings. The records of the Grafton well indicate that the Archean is overlain by Cambrian sandstone. However, the records on which identification is based are somewhat doubtful. If they are correct, there would seem to be a very great undulation in the old Archean floor. Farther north in Canada

Plate XXXVII.



Irrigating a Wheat Field.

the Silurian seems to rest on the Archean with no intervening Cambrian. This would indicate a local condition in which the Cambrian of the Grafton well (if it be truly Cambrian) occupied a depression in the Archean floor.

Silurian.—As has already been intimated, a portion of the Red river valley includes a deposit of Silurian rock under the thick covering of gravel and glacial debris. It is probably absent in the western portion of the valley, but it doubtless extends, more or less continuously, beyond the northern boundary of the state, for its outcrops are found about Lake Winnipeg in Canada. In the northern part of the state fragments of characteristic, fossiliferous, Lower Silurian limestone are very common in the drift. It is hard to give any approximate southwestern limit of Silurian but it may not be far from Grand Forks, for a layer of limestone, apparently Silurian, about one foot thick was found in a well about 380 feet below the surface. This deposit may indicate nearness to the limit of deposition in the old Silurian basin. This basin seems to have rapidly deepened, however, toward the north, for in the well at Grafton the total thickness of the Silurian is recorded as about 317 feet. It increases in thickness toward the north and probably toward the west, as at Rosenfield, in Canada, about sixty miles north of Grafton, the Silurian is said to have reached a thickness of 892 feet.

Toward the west its extent is uncertain, and where outcrops occur, across the boundary line, the Silurian rocks lie in nearly a horizontal position upon the Archean. The occurrence of outcrops of Silurian limestone to the north might be predicted from the large proportion of this material found in the gravel, sand and clay of the drift of the Red river valley and the gravel deposits farther west. Large boulders of the limestone are not common, but the gravel and clay in the northeastern part of the state frequently contain as much limestone as granite and gneiss, a fact which has no small effect on the fertility of the soil in this region.

Cretaceous.—Between the Silurian and Cretaceous is an unconformity and apparently a large gap in the geologic series. If other formations are present between the Silurian and Cretaceous westward, they are very deeply covered with the later deposited material.

The Cretaceous formations found so extensively in North Dakota are part of a great belt occupying a large part of the Great Plains and extending from the Gulf of Mexico northwestward toward the Arctic regions. The great extent and thickness of these deposits in North Dakota, their influence upon the soil, and their connection with the artesian and shallow well water supply render them worthy of a somewhat detailed description.

The formations of the Cretaceous which are so well represented in the Great Plains region have been classified as follows:

Cretaceous........................
- Laramie
- Montana
  - Fox Hills
  - Pierre
- Colorado
  - Niobrara
  - Benton
- Dakota

All of these subdivisions are found within the limits of North Dakota, though but a portion of them outcrop on the surface. The Cretaceous series is probably best developed in the central portion of the state, from east to west. In the eastern part the upper group is not found, while the middle and lower groups are not difficult to reach in well borings. In the western and northwestern parts of the state the upper groups commonly appear, and are doubtless underlain by the earlier formations.

The Dakota.—This stage consists so largely of a sand deposit which has become more or less hardened that it is known as the Dakota sandstone, and it thus differs markedly from the overlying formations, which are chiefly clays. No surface exposures of the formation are found in North Dakota, but its relative position and, in a limited way, its extent have been observed from the boring of artesian wells in various parts of the state. From the records at hand it appears to underlie the upper Cretaceous and drift over practically all the state, from the Red river valley on the east to the western limit, and from the Canadian line into South Dakota. Information regarding the thickness of the group is meagre. From well records the Dakota appears to be very thin in the eastern portion of the state, but it increases rapidly in thickness toward the central and western parts. It ascends gradually toward the western highlands, and in many places in the Black Hills of South Dakota and along the mountains it outcrops at the surface. These surface exposures of the Dakota sandstone, which along the Rocky mountains aggregate many thousands of miles in area, are generally considered the gathering grounds for the artesian waters of the Great Plains.

Benton and Niobrara.—These formations immediately overlie the Dakota sandstone over a large part of that great section of the plains in which the latter is found.

In North Dakota they are well developed in the central and northern part of the state, but seldom appear along the eastern border. They are readily distinguished from the Dakota, as they are composed principally of blue clays and shales, and are generally of very fine material. Sand is occasionally present in these deposits, but not in any large amount. The clays and shales of the Niobrara and upper portion of the Benton are often rather strongly impregnated with carbonate of lime, and in a few places in South Dakota they become quite pure chalk.

In the central portion of the state the total thickness of the Benton and Niobrara reaches probably from 500 to 800 feet, and the variation in thickness, within considerable areas, seems not to be very great. Over most of the state the Benton is covered with Pierre and with drift, although in a few localities outcrops of the Pierre are found. In the northern part of the state, in deep cuts along the Pembina river, the top of the Niobrara is occasionally seen beneath the banks of Pierre shales, 350 feet or more below the general level of the surface. Along the eastern borders of the Dakota sandstone the Benton and Niobrara do not appear, the Pierre seeming to overlap and rest directly upon the Dakota. In South Dakota and Nebraska are many exposures of both Benton and Niobrara, the Pierre being relatively thinner and less uniform in its extent in those states than in many places in North Dakota. As nearly all our information regarding the group in this state has been derived from artesian well borings, there has been little opportunity to study the fossil character of the deposit; but, from the apparent similarity in the conditions of the deposition, it is safely assumed that the fossils do not vary greatly from those found in South Dakota exposures.

In this state both the Benton and the Niobrara are characterized by dark blue and black shales, frequently charged with lime and often carrying iron pyrites, fragments of coal, alum and crystal gypsum, all in very small quantities.

Pierre.—This division comprises a great deposit of clays and argillaceous shales, bluish-gray in color, very fine and uniform in texture and almost free from sand, lying immediately above the Niobrara and usually in perfect conformity Its lower portion is somewhat darkened by the presence of carbonaceous matter. These shales do not carry much carbonate of lime, in which they differ markedly from the Niobrara, but they do often contain thin seams of sulphate of lime, nodules of iron pyrites and alum. Probably in no part of the state has the greatest thickness of the Pierre been penetrated. Along the deepest cuts formed by the Big Pembina river the bottom of the Pierre is reached at about 350 or 400 feet below the surrounding country; but the elevation of the land increases considerably to the northwest, and in this region, as well as in others, it may reach a total thickness of 600 feet or more. Toward the east, however, the Pierre gradually thins out, until in the Red river valley only its debris is found.

At the international boundary the Pierre is seen just west of the Red river valley, where it forms nearly all the material of that conspicuous hilly escarpment known as the Pembina mountain (see figure 14). These hills form a very remarkable series of highlands, which increase slightly in elevation toward the northwest and stretch away toward the south in a gradually descending rolling plain. The Pembina mountain, so-called, is really only the sharply eroded eastern edge of the Cretaceous formations, mostly of Pierre, which underlie the Turtle mountains as well as the Pembina mountains and all the intermediate country. Among the hills and along the banks of spring brooks and lakes of the Turtle mountains the Pierre is constantly outcropping; and from this northern highland southward through the central part of the state it is always found underlying the varying deposits of drift. It is obtained from the deep well borings, is seen along many streams, and frequently small fragments of its hardened, shaly, blue clay occur on the surface of the drift ridges. This is continually observed in the whole of the Devils lake basin. To the east many of the smaller streams cut into the Pierre, and the formation is clearly seen along the banks of the Sheyenne and James rivers.

Like the other divisions of the Cretaceous, the Pierre extends over a great area beyond the limits of North Dakota, chiefly southward in South Dakota, Nebraska, Colorado and adjoining states.

The Pierre is easily recognizable by the color and texture of the clays and shales, but fossils are not entirely lacking, and several forms are found along streams in many places in the central part of the state. The more common fossils are *Baculites ovatus, Inoceramus, Scaphites* (*S. nodosus* Owen, *S. nicolletii* Morton). These fossils are often partly disintegrated and very commonly highly discolored by iron. Although many other forms may occasionally be found, the Pierre in North Dakota must still be considered rather barren of fossils.

There are no formations which play so important a part in the geology of North Dakota as those of the Pierre. Vast accumulations of the clay and shales of this stage are found throughout a large area in the central part of the state, and its debris forms much of the soil and subsoil in the glacial deposits scattered over all the eastern half. It is also a factor in determining the underground water supply in the central part of the state. It forms very generally the confining bed for the shallow wells in the eastern and central parts of the state, and water is generally found in the sand and shale debris deposited upon or interstratified with the Pierre.

Laramie.—The Laramie extends over a large portion of the state west of the Missouri river. The deposits consist principally of clays, some of which are excellent as fire and white-ware clays. It has already been briefly reviewed in an earlier chapter.

Drift.—The drift deposits in many localities of North Dakota form important factors, not only in the surface topography, but as well in the geologic and economic conditions. The water supplies of considerable areas are materially affected by the presence or absence of drift. This is especially true in the Devils lake drainage basin, and some of the conditions, especially of the topography, are illustrated in the plates and maps showing the drainage and morainic deposits. The drift, indeed, may be considered as one of the most characteristic deposits within the state of North Dakota, particularly that portion lying east of the Missouri river. On account of the importance of this formation in the Devils lake basin, it will be well to consider somewhat in detail the conditions under which the drift was deposited and its effect upon the present Devils lake basin and its water supply. The drift in this region is made up largely of sand and clay, mingled with gravel and boulders, and presents a heterogeneous mass totally unlike the sedimentary formations upon which it lies. Anyone who will thoughtfully consider the appearance of the surface of nearly all the eastern part of North Dakota will be impressed by the fact that some widely operative and powerful agency has, within a comparatively recent geological period, been shaping its features and accumulating, mingling and distributing the immense amount of unconsolidated material which covers to a considerable thickness the earlier stratified formations.

The embedding material is usually blue and yellow clay in thick sheets, sometimes alternating with beds of sand and gravel, in both of which are scattered large blocks of various kinds of rocks, sometimes weighing several thousand pounds. These boulders are frequently smoothed and scored with fine parallel scratches. A knowledge of the character of these rock masses and a familiarity with some of the rocks outcropping farther north, in Canada, leads to the belief that the debris was transported from northern regions. Much of the limestone found in the drift in the northern part of the state was undoubtedly taken from the beds which outcrop about Lake Winnipeg. A study of well excavations and of channels of stream erosion shows that this drift material was spread over an old land surface. In some places in the Red river valley drift and alluvial deposits reach a depth of 300 to 350 feet. In the northern and central part of the state the thickness is commonly from thirty to 100 feet.

The character of these various drift deposits indicates that a very large area in North Dakota was, at a late geological period, covered by a great, slowly moving ice sheet, similar to that which now covers a large part of Greenland, which stretched far away to the north into Canada. This vast ice sheet, which in its northern portion at least must have been very deep, tore away exposed rock ledges, and enveloped and bore along with it the loose material with which it came in contact. This debris was frozen into the ice, and under the enormous weight above it became a mighty grinding power. As the ice sheet moved onward from the north, slowly but irresistibly, the enclosed rock masses were worn away to smaller fragments, pebbles, sand and clay, and all mixed with the sand and clay and soils of the surface over which the ice moved. Thus was formed, during the centuries of the glacial period, an enormous amount of this rock refuse, which, with the return of a warmer climate and the melting of the ice sheet, was intermingled and spread far and wide.

This drift material, by reason of its variety of composition and depth of deposit, was well calculated to become the formation of the rich soil so characteristic of the eastern and central parts of North Dakota.

With a change in climatic conditions the ice began to melt along its southern border, and the water formed by the melting, being banked on the north by the great ice barrier, gradually accumulated in a glacial lake along the southern boundary of the sheet. As the glacier continued its retreat to the north, the area and depth of the lake increased, and the water, spreading out over the Red river valley and finding no other outlet, at last overflowed the height of land near Lake Traverse, making its way through that lake and Big Stone lake into the Minnesota river and thence into the Mississippi river. When the ice had melted far enough toward the north, a natural outlet was opened through Lake Winnipeg and Hudson bay, and the present valley of the Red river was begun. The total area covered by this great lake, known as Lake Agassiz, has been estimated by Warren Upham* at 110,000 square miles, over which the water often reached a depth of 500 to 700 feet. At last the ice sheet had retreated so far that it left open the Nelson river, thus affording an outlet through this river and Lake Winnipeg into Hudson bay. From this time Lake Agassiz was rapidly drained. In the lowland of the Winnipeg basin, however, a large body of water was left, a portion of which forms the present Lake Winnipeg.

This great body of water has recorded its presence in three way: By lacustrine sediments, by extensive alluvial and delta deposits, and by corresponding extensive erosion. The fine silt and clay which are characteristic of the Red river valley were deposited by the waters of Lake Agassiz and the many glacial rivers which brought debris into this basin from the surrounding higher lands. The water of the glacial Red river gradually narrowed, but in the central portion of the valley, being much deeper, it remained a longer time, and thus gave opportunity for a thicker deposit of sediment than is found along the old lake margin. Warren Upham has traced a series of beaches marking clearly the extent of Lake Agassiz at its various stages.

The streams which flow through the lacustrine sediments usually have narrow and shallow banks, but the valleys of those streams which flow into the basin of Lake Agassiz are commonly deep and wide, showing much erosion. This is particularly noticeable of the streams flowing from the Cretaceous highlands on the west, for example, Park river, Tongue river, Little Pembina and the Pembina rivers. Along the eastern escarpment of the Pembina mountains the erosive action of the old lake is clearly seen in the almost cliff-like ascent of the Cretaceous tableland.

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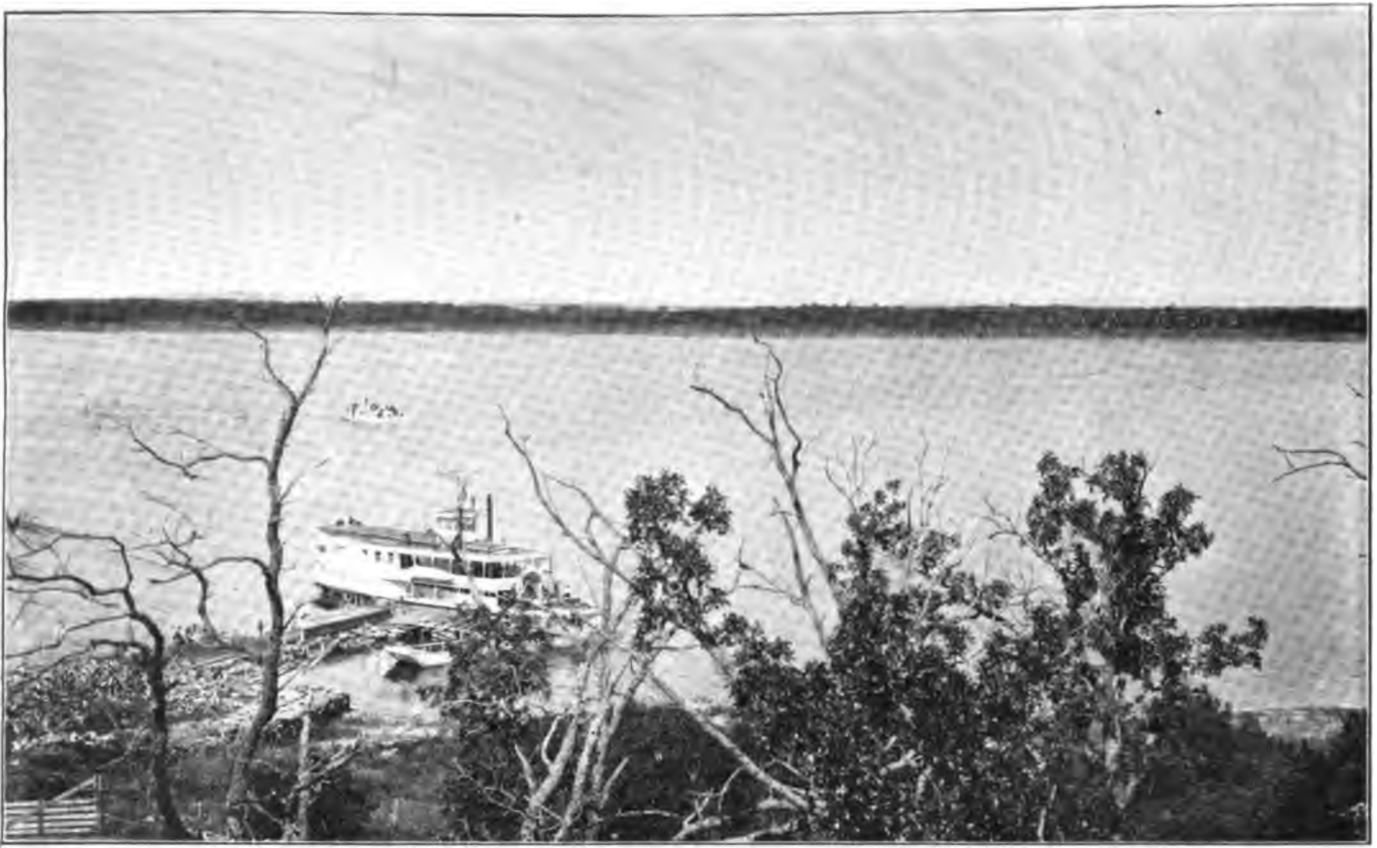
*The Glacial Lake Agassiz, by Warren Upham; Mon. U. S. Geol. Survey, No. XXV, 1895.

Lake Agassiz was not the only glacial lake by which the surface of the level prairies of North Dakota was modified. In the central part of the state there were probably several lakes at various periods following the glacial epoch which were formed from the melting of arms of the ice sheet. One of the most important of these was glacial Lake Souris. Devils lake and its immediate drainage basin is doubtless a remnant of one of these lakes. The Sheyenne and James rivers probably were started and the high bluffs along the western portion of these streams washed out during the time when districts to the north, about Devils lake, and to the west, being flooded by the melting ice, were drained of great quantities of water by these rivers. All through the eastern and central portion of the state the ice sheet, the lakes and the river torrents formed by melting ice, exerted a powerful influence in giving fertility to the soil and final shape to the surface of our North Dakota prairies.

DEVILS LAKE

The most characteristic feature of the region under discussion is Devils lake, which occupies a basin formed largely by morainic ridges. As shown on the map, it lies along Ramsey and Benson counties, with its length extending east and west, as illustrated in plate XXXVIII. The length of the lake, including the arms which properly belong to its present stage, though some of them are nearly dry or separated by portions of land, is about twenty-four miles, and the width averages perhaps between four and seven miles. Its shore line is exceedingly long, owing to the numerous bays and other irregularities, and it is probable that it will reach several hundred miles.

The southern shore of the lake, which is often very thickly strewn with large boulders, rises rapidly into a high rolling country, whose surface is broken by numerous steep knobs, some of them 200 to 275 feet above water level. The western



View of Devils Lake.

part of this tract is included in the Sioux Indian reservation. Northward the land rises in gentle swells, gradually increasing in elevation, until it reaches the rolling drift deposits just north of the city of Devils Lake and Grand Harbor. Toward the northwest is a similar gradual elevation of rolling prairie for nearly forty miles.

That there was unquestionably a time in the early history of this lake when it was several times larger than it is at present is evident in several ways. At many places along the south shore there are found, well up on the steep hillsides which begin near the lake, large boulders which present a peculiar parallel arrangement, apparently the result of the expansive action of shore ice during the winters and springs. The boulders were pushed into their present positions when the water was high, and this crowding up of large rocks continued year after year. These marks of the old water level are now seen twenty or thirty feet above the present water level. Such an elevation of the water surface would of course extend the lake over a much wider area to the west and north.

This condition is also indicated by what are undoubtedly old shallow shore lines from six to ten miles north and west of the lake. In appearance some of these shores are not unlike beaches of old Lake Agassiz, east of Larimore. The character and arrangement of the clay, sand and gravel are indicative of shallow water. Wells dug along these shores pass through varying thicknesses of such lacustrine deposits, depending on the surface elevation and distance from the lake. From a study of the formations penetrated in about forty or fifty wells in the vicinity of the lake, deposits apparently lacustrine are found immediately above morainic debris on the higher portions, or in the lower places, mixed with drift and fragments of Pierre shale.

Another evidence of the former wide extent of this lake is afforded by the character of the water in the wells near it. When the lake was at its highest, its water, largely derived from the melting snow and ice, was fresh, it was fed by numerous large streams and probably for a short time had southeastern outlets. As the lake decreased in size, its waters became more strongly impregnated with salts left by the evaporation of the incoming surface water. The soil and clay which had been under shallow water for a short time stored up a small amount of salts, while those nearer the center of the basin and deeply covered with water for a much longer time stored up correspondingly larger amounts of the salts. These salts are now being redissolved in the well water. A large number of samples of water from wells at different distances ranging from one-half mile to six miles from the lake, but clearly within the immediate lake basin, were examined by the writer, by chemical field tests or by rapid laboratory determinations, with a special view to ascertaining the relative amounts of alkalies, chlorides and other salts. It was thought that such an examination might not only give some hints of value in determining the best location for wells, but that it might throw some light on the former extent of the lake bed. These chemical tests show that in general the percentage of chlorides and hydrogen sulphide increases as the lake is approached. In nearly all cases the water which is strong in chlorides (mostly common salt) is obtained from wells located on low land or near the lake, while that containing a small amount of chlorides is generally from wells located on high land. To exhibit this fact more clearly the following table has been prepared, showing the relative amounts of salt and alkalies in the water, together with the elevation of a number of wells about the lake. Corresponding numbers will be found on the map, and from these the wells can be readily located:

TABLE SHOWING RELATIVE SALINITY OF WELLS NEAR DEVILS LAKE

No.	Depth of Well Feet	Elevation	Relative Amount of Salts		
			Chloride *	Alkalies	Soluble Sulphides†
1	22	High		Little.	
2	119	Very high	Trace.		
3	52	Medium	Strong	Little	Trace
4	29	High	Trace		Much
5	40	Low.			Much
6	40	High	Little.	Trace	Much
7	36	Low	Strong		Much
8	107	High	Little	Trace	Little
9	33	Low	Strong	Trace.	
10	30	High.	Little	Little	Much
11	22	High	Trace	Trace	Much
12	72	Very high	Trace	Trace	Trace
13	38	Medium	Strong	Trace	Trace
14	40	Low	Strong	Trace	Little
15	29	Low	Strong	Strong.	
16	46	High	Trace	Trace.	
17	25	Medium	Strong	Trace	Little
18	38	High	Trace	Trace	Trace
19	32	Low	Strong	Trace	Much
20	32	Medium	Strong	Trace	Much
21	24	Medium	Little.	Little.	

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*Principally common salt. Though these are not expressed in exact quantities, the amounts are relatively correct.

†Including hydrogen sulphide.

A careful study of the shore line and the gravel and other deposits about Lake Irvine and to the southeast shows very plainly that the small lakes north of Devils lake were also very much larger at some time in their history. There is little doubt that Lake Irvine, at no very remote period, extended from one mile to three miles farther east, and stretching toward the south, widened out irregularly three or four miles more towards the southeast. At this time Lac aux Morts, Twin lakes, and Dry lake were probably connected and formed one sheet of water, which may have been continuous with Cavanaugh and Sweetwater lakes, thus forming a large body of water which stretched out with irregular shore line toward the southeast, nearly parallel to the present Devils lake, presenting an appearance similar to the Devils lake of today. This old lake and Devils lake were doubtless connected by a long, narrow bay, filling all the low land of the coulee bed between Lake Irvine and Devils lake.

It is thus evident that there has been a gradual reduction in the volume of water in Devils lake and surrounding lakes for a very long time, perhaps for an epoch following soon after the glacial period. From the observations and reports of those who lived about the lake for years, and especially from the records of Capt. E. E. Herman, it appears that the water has been decreasing in depth and area for the past ten years. Since 1883, at various times, according to the best estimates obtainable, the lake has been from four to nine feet lower than at that time. Arms of the lake on which steamers were accustomed to ply ten years ago have now become dry, or so low that boating on them is impossible. A few years ago steamers could run into the city of Devils Lake or Minnewaukan, but at present they do not attempt to come within several miles of either place.

In the fall of 1896 the surface of the water was found by leveling to be 39.8 feet below the top rails at a point on the Great Northern railway, the altitude of which is given at 1,469 feet above the sea, which would leave the water in the lake at that time 1,429.2 feet above the sea. At the same time soundings were taken of the central part of the main lake, and from nine soundings taken between the Chautauqua grounds and Fort Totten, at various points not within a mile or more of the shore, an average depth of 25.5 feet was obtained. The greatest depth of water found was near the center of this part of the lake, and amounted to 29.3 feet.

Considering the historic and prehistoric records of the lake, the question which naturally arises is, will the lake continue to decrease in size until, like most old glacial lakes, it becomes quite dry or at least until it is very much further reduced? To this, of course, no positive answer can be given. In order to form an intelligent opinion on the subject one must take into consideration the character of the formation of the retaining basin, the area of drainage, the amount of rainfall and the proportion of water which finds its way into the lake. There being no outlet, practically the only means for decrease is by evaporation, and from a study of the geologic conditions it is evident that there is no chance for subterranean drainage, to any considerable extent, other than into this basin. Indeed, the arrangement of the blue shale (Pierre) underlying the drift provides a very perfect gathering bottom for surface water, and the fact that over large areas this shale has but slight dip still further aids in retaining the percolating water. There is no doubt but that during the last fifteen years the breaking up of so much of the thick prairie sod has had a marked influence in reducing the volume of water flowing in Devils lake. The plowing destroys the natural thatch of grass which covers the porous soil and on which so much of the water runs. It exposes the dry soil which so readily imbibes a large proportion of the moisture precipitated; and it forms by the roughened surface, a very great obstruction to the flowing water. The conditions for the last few years have all been very favorable to the reduction of the run-off water, and there is no reason to believe that the lake will be able to regain permanently any considerable portion of its lost area. A further reduction of its volume may even be expected as still more prairie land is put under cultivation, but this must necessarily be at a much slower rate than heretofore, and there is reason to believe that it will not cause the water to fall much below its present limits in the central, deeper portion of the lake.

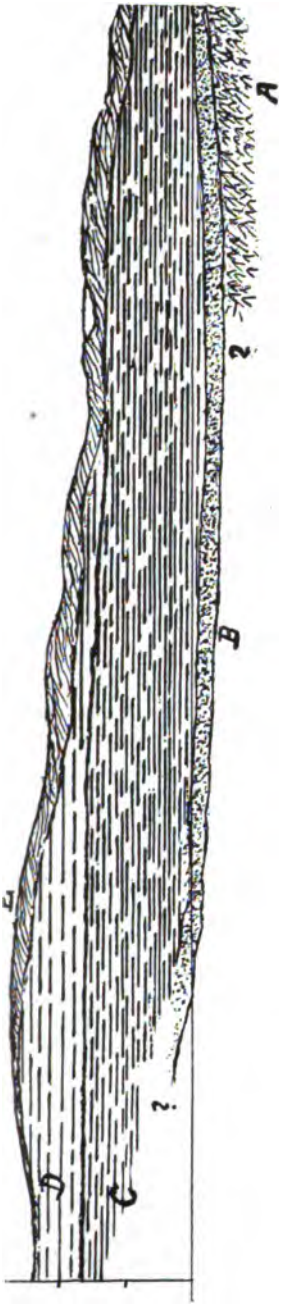

Fig. 17. Section showing water bearing strata.

WATER SUPPLY

The area naturally tributary to Devils lake is probably not far from 4,000 square miles. With such a gathering surface it would seem that there should be no lack of water if but a small fraction of the annual rainfall reached the lake; but the general inclination toward the lake is so gentle that the streams flow very sluggishly, and thus there is opportunity for a very large proportion of the water of the catchment basin to evaporate or soak into the soil before it reaches the lake.

The geological formations of the district have already been described, but may be summarized here as follows: Starting with the Dakota sandstone, whose total thickness here is not known. the deposit next above is the Benton, composed of dark clays and shales; above this is the Niobrara, usually highly calcareous, but represented in this locality by slightly calcareous layers of dark blue slate and clays; next is the Pierre, represented by similar clays and shales; and upon the Pierre the drift is spread for a thickness varying from twenty to fifty feet. A section from the artesian well in the city of Devils Lake, the elevation of which is from 1,460 to 1,470 feet above the sea level, gives the relative thickness of the different formations approximately as indicated by the accompanying figure.

The underground water supply of this region is derived from two formations. The water from the deep artesian well comes from the Dakota sandstone; that of the shallow wells is found chiefly in the till at the top of the Pierre or in the upper layers of the Pierre itself. A large number of artesian wells have been bored in the southern and eastern parts of North Dakota, but only an occasional well has been attempted in the northwestern part of the state. In the Red river valley the artesian wells usually give a small flow from beds lying 100 to 300 feet below the surface, but the water from most of these wells has little or no pressure. The wells of the south central part of the state, however, all give a large flow at from 400 to 1,200 feet, with good pressure at the surface. The artesian water at the town of Devils Lake flows with some force, furnishing about forty gallons per minute. The water commonly carries a small amount of fine Dakota sand and is rather strongly impregnated with salts. The following is an analysis of this water, made by James A. Dodge, formerly professor of chemistry at the University of Minnesota. In addition to the substances reported there are found traces of borates, bromides and organic matter.

ANALYSIS OF WATER FROM ARTESIAN WELL AT DEVILS LAKE

	Grains Per Gallon
Sulphate of sodium	94.62
Chloride of sodium	86.46
Carbonate of sodium	41.11
Carbonate of potassium	4.62
Carbonate of lithium	0.67
Carbonate of calcium	1.56
Carbonate of magnesium	1.01
Carbonate of iron	0.03
Silicia	0.56
Total dissolved solids	230.64

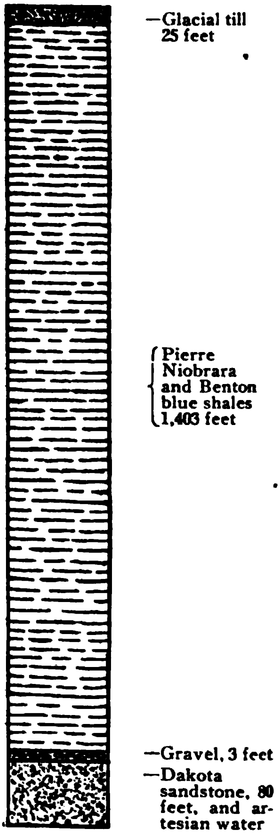
—Glacial till 25 feet
Pierre Niobrara and Benton blue shales 1,403 feet
—Gravel, 3 feet
—Dakota sandstone, 80 feet, and artesian water

Fig. 18. Section of artesian well at Devils Lake.

Owing to the low pressure and to the depth of boring required to secure the flow of water, it has been found too expensive for individuals to sink artesian wells in the Devils lake region. For this and other reasons the discussion of artesian wells will not be taken up in this paper.

USE OF WELL WATER IN IRRIGATION

The water found in the till on top of the gray shale of the Pierre, and reached by shallow wells ranging usually from thirty to seventy feet in depth, is of great importance, not only on account of the lack of other water supplies, but because of its great abundance and the possibility of its use for irrigation as well as for household purposes. A study of the surrounding topographic and geologic conditions and an examination of about 100 wells in this district indicates that the quantity of water thus stored is vast, and that it will be amply sufficient to meet all the demands that can be made upon it until the population has increased several fold over that of the present. The flow of water in these wells is very slow, because of the compact nature of the strata through which the water must pass, and the daily supply of the wells when pumped to their limit may seem small compared with the rapid flow of artesian wells and of large springs; but the important point is as to the capacity of the underground reservoir.

If, as has been said, the reservoir is capable of supplying a great amount of water, the question naturally arises as to whether the shallow wells of this region can be used for irrigation. Those unfamiliar with the value of irrigation farming are sometimes inclined to regard with suspicion statements as to the productive possibilities of any region where irrigation is practiced or where it might profitably be used, but those who have had experience or who have made a careful study of the subject are quick to recognize the advantages.

The value of irrigation is not confined to arid or barren regions. Indeed, its greatest benefits can be derived only where the soil is naturally productive and the climate suited to the growth of the special crops to be cultivated. In this country and in other countries irrigation is frequently carried on in a small way with the largest profit in sections where the total rainfall is abundant, as by means of artificial applications the moisture can be furnished at times when it is most needed by the crops and to those portions of the land most needing it, thus advantageously supplementing nature's method.

The foregoing description of the topography of this district shows it to be a beautifully rolling prairie, remarkably well adapted to agricultural pursuits. The soil and subsoil are rich and enduring. Both are derived from Cretaceous deposits mixed with fine rock refuse of Archean and Silurian formations, and all mingled with a considerable proportion of vegetable mold. The soil thus comprises a good body clay, with a sufficient amount of fine sandy material to make it reasonably porous, and with lime and other ingredients to keep it "warm and sweet," while the carbonaceous matter renders a valuable aid in the plant food supply. The fertility of this soil is well proven by the enormous crops harvested in seasons of abundant rainfall. While in no respect an arid district, there is frequently a portion of the growing season during which but little rain falls, and then the application, once or twice, of a very small amount of water to the land would undoubtedly increase the matured crop from 20 to 50 per cent, an increase which would mean to the farmer the difference between a profitable season and one of little or no gain. It is not, therefore, with the intention of urging the farmer to rely upon irrigation, but that he may be led to supplement the rainfall at just those periods of greatest need and thereby save a large per cent of the natural yield, that attention is here called to the possible use of shallow wells.

In considering the use of both artesian and shallow well water, the question is frequently raised as to the effect of the dissolved mineral matter upon vegetation, and reference is sometimes made to the vegetation occurring about alkali spots as illustrating the possible result of the use of such mineralized waters. The water of wells is never so strongly alkaline as is the water in these places, and the amount of such deposits as would be left by the occasional and reasonable use in irrigation, even of strongly impregnated artesian water, could not cause an appreciable accumulation of alkalies in the soil. The alkali spots which are occasionally seen on the prairies and alkali waters are probably in a measure due to the same cause. For years before the settlement of the west prairie fires destroyed the summer's growth of grass, leaving upon the surface the ash or mineral constituents of the vegetation, consisting largely of potassium and sodium carbonates. These compounds, being soluble in water, were dissolved by the rain and melting snow and carried to lower places. During the warm summer much of the water evaporated, and an accumulation of its various soluble salts, especially alkaline carbonates, was left. Thus in low places this alkaline matter has been accumulating for years, and in this condensed form proves injurious to the vegetation.

The small amount of alkalies in the well waters of these prairies is probably also due in a large measure to the ash of burned prairie grass, and represents that proportion which was carried downward through the soil by imbibition. Water obtained at or near the top of the Pierre formation is especially liable to be alkaline, owing probably to the accumulation in this compact clay formation of salts thus carried downward. As prairie fires cease and the present pernicious practice of burning straw is abandoned, the alkali spots and the alkali water will doubtless become improved.

The following tables give the results of partial analyses of water obtained during the field work, the samples being considered as typical of the waters of the region. The first table shows, in grains per gallon, the chlorine estimated as equivalent to sodium chloride, the hardness equivalent to carbonates and sulphates of lime and magnesia, and the alkaline ingredients including some carbonates of lime and magnesia. In the second table there is presented more complete data as to the location of the wells, the depth of strata penetrated, the quantity of water obtained, and the amounts of salts, alkalies and soluble sulphates, these being given in relative terms, having been determined from field tests.

From these analyses it is evident that the waters do not contain alkalies or mineral salts in such quantities that injury to the soil would be caused by their use in irrigation.

PARTIAL ANALYSES OF WELL AND OTHER WATER IN THE DEVILS LAKE REGION

		Grains Per Gallon			
		(1)	(2)	(3)	Total
Name and Number		Chloride	Hardness	Alkalies	Solids
1	Tollef Tollefson	67.07	560.00	10.60	993.20
2	Devils Lake water	79.60	227.50	19.08	635.90
3	Sheyenne river	1.65	15.00	29.68	58.50
4	Frank Williams	17.63	22.50	6.36	449.70
5	Baker's well, (near Oberon)	23.90	130.00	10.60	466.60
6	Frank Wood	3.63	21.00	12.72	40.30
7	Walter Falgeson	4.12	7.50	25.44	81.20
8	Wilcox, north of Leeds	0.49	18.00	4.24	......
9	Mauvaise coulee	1.81	17.50	......	62.30
10	Linberberg	1.32	19.00	6.36	37.90
11	Andrew Grasser (over 500 ft. deep)	111.90	13.00	12.72	161.70
12	Jacobson	14.67	79.00	23.32	231.00
13	Phillip Cocking	0.49	17.00	8.48	87.80
14	L. A. Johnson	5.44	23.00	29.68	98.90
15	C. E. Engre	4.61	54.50	19.08	149.60
16	Goldberg	4.12	44.00	4.24	78.30
17	Maristeau	9.39	42.00	6.36	117.00
18	Wimbledon artesian*	80.42	105.00	6.36	257.80
19	Monstad	6.10	34.30	8.48	89.40
20	Conway*	219.18	15.00	31.80	326.90

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(1) Estimated as equivalent to sodium chloride.
(2) Equivalent to carbonates and sulphates of lime and magnesia.
(3) All ingredients including some carbonates of lime and magnesia, estimated equivalent to carbonate of sodium.
*Not in this region.

TABLE OF FIELD DATA ON WELLS OF THE DEVILS LAKE BASIN

Number	Name	Location			Depth	Feet of Soil and Yellow Clay	Feet of Blue Clay	Feet of Sand and Gravel	On High or Low Land	Quantity of Water	Salt	Alkalies	Soluble Sulphides or Hydrogen Sulphide
		Section	Township	Range									
1	Treleaven........	8	153	67	22	6	16	1	High.....	Plentiful.	....	Slight.	
2	Pierson,.........	..	....	..	119	12	68	39	Very high	Plentiful.	Trace.		
3	Atkinson........	20	154	64	52	6	44	2	Medium..	Limited..	Strong..	....	..Trace
4	Vanlieu..........	18	154	64	29	....	....	....	High.....	Plentiful.	Trace...	....	..Much
5	Swanson........	12	154	65	40	10	30	....	Low......	Plentiful.	....	....	..Much
6	Swanson........	½ mile n. e. of Grand Harbor			40	....	....	....	High.....	....	Little...	....	..Much
7	Grand Harbor....	..	....	..	36	....	....	....	Low......	....	Much...	....	..Much
8	Bryn Bros,......	20	154	65	107	....	....	....	High.....	Limited..	Slight..	Trace...	..Some
9	....	22	154	65	33	....	....	....	Low......	....	Much...	Slight.	
10	Manseau.......	25	154	65	30	....	Largely	....	High.....	Plentiful.	Little...	Little...	..Much
11	Caley............	½ mile w. of Grand Harbor			22	....	....	....	High.....	Plentiful.	Trace...	Slight...	..Much
12	....	2 miles s. w. of Dry lake			72	....	....	....	Very high	....	....	Trace.	
13	Gressen..........	33	155	65	38	8	24	6	Medium..	Plentiful.	Much...	Slight...	..Trace
14	Eisenhour.......	½ mile s. w. of above			40	....	....	....	Low......	Plentiful.	Much...	Trace...	..Little
15	Jacobson........	14	154	65	29	....	....	....	Low......	V. large	Strong..	Strong.	
16	Dixon...........	9	154	66	46	25	20	1	Medium..	....	Trace.		
17	Noltmeier.......	Churchs Ferry			25	....	....	....	Medium..	Plentiful.	Much...	Slight...	..Little
18	Kirkeide.........	30	155	66	38	....	....	....	High.....	Plentiful.	Trace...	Trace.	

TABLE OF FIELD DATA ON WELLS OF THE DEVILS LAKE BASIN—Continued

Number	Name	Location			Depth	Feet of Soil and Yellow Clay	Feet of Blue Clay	Feet of Sand and Gravel	On High or Low Land	Quantity of Water	Salt	Alkalies	Soluble Sulphides or Hydrogen Sulphide
		Section	Township	Range									
19	Knuteson	½ mile east of Churchs F'ry			32	....	Largely	....	Low	Plentiful	Much	Trace	Much
20	Gunn	33	155	66	32	8	24	....	Medium	Plentiful	Much	Trace	Much
21	Brown	3	153	67	24	20	......	4	Medium	Limited	....	Slight.	
22	Gunhus	35	156	68	20	....	......	....	High	Plentiful	Little.		
23	McDonald	26	155	67	24	18	3	3	Low	Plentiful	Trace	Slight.	
24	Anderson	1	154	67	19	12	6	1	High	Plentiful			
25	Kildahl	5	156	66	35	17	15	3	Medium	Plentiful	Slight	Slight.	
26	Dohaney	..	....	..	22	....	....	....	High	Plentiful	....	Slight.	
27	Wilson	13	154	65	40	9	30	1	Medium	Plentiful	Little	Slight	Little
28	Mark	2	154	65	32	12	18	2	High	Plentiful	Trace	Little.	
29	Grand Harbor	..	....	..	40	....	....	....	Medium	....	Much	Little.	
30	Grand Harbor	..	....	..	36	12	24	1	Low	Plentiful	Much	....	Much
31	Blanchfield	17	154	65	40	....	....	....	....	Limited	Slight	Slight	Strong
32	Bryn	..	....	..	37	....	....	....	Medium	Plentiful	Much	Slight	Much
33	Hoadley	..	....	..	52	....	....	....	Medium	Limited	Trace	Strong	Much
34	Fitzgerald	..	....	..	36	....	....	....	Medium	Limited	Little	Much	Much
35	Anderson	..	....	..	47	L'gly	....	....	High	Limited	Trace	Slight	Trace
36	Richardson	17	154	65	39	....	....	....	Medium	Plentiful	Trace	Trace.	
37	Enger	25	156	66	30	16	14	....	Medium	Plentiful	Little	Much.	
38	Tollefson	4	154	66	25	....	....	....	High	Plentiful	Much	Trace	Much
39	Barrett	2	155	66	36	20	12	4	Medium	Plentiful	Little	Trace	Trace
40	Mitchell	16	155	66	28	9	19	1	Medium	Plentiful	Little	Trace	Little

41	Goldbery........	..	....	..	40	12	27	1	High.....	Plentiful	Little..	Trace.	
42	Johnson........	19	156	68	65	....	....	....	High.....	V. large	Little..	Much.	
43	Maristeau.......	17	155	68	70	....	Largely	....	Low......	V. large	Much..	Little.	
44	Cocking.........	34	155	68	63	and sand							
45	Grasser (water at 30 ft., 190 ft. and 400 ft.)....	Minnewaukan			532	34 26	29 20	.... 4 and shale to 532	Very high	V. large	Trace..	Little.	
									....	Large	Much..	Slight.	
46	Rugby..........	..	....	..	35	....	....	....	....	Plentiful			
47	Williams........	13	151	68	20	20	....	....	Medium..	Plentiful	....	Slight.	
48	Mathews........	34	151	67	22	22			Medium.				
49	Yeager..........	18	151	67	10-15	10	....	....	Low......	Plentiful	....	Slight.	
50	Chance..........	11	151	68	16	10	6		High.....	Plentiful	....	Much.	
51	Duncan.........	2	151	68	20	20	....	....	High.....	Limited			
52	Monogram......	26	152	68	18	18	....	....	High.....	Plentiful			
53	Braithwaite.....	6	151	68	10-15	10	....	....	Low......	Plentiful	....	Slight.	
54	Lestenberger....	..	....	..	72	....	....	....	High.....	Limited	Trace	Slight..	Trace
55	Englehorn......	W. of Ch. Ferry			100	....	....	....	....	V. large			
56	Oleson..........	12	154	67	25	8	17	1	Medium..	Plentiful			
57	Meyer...........	1	156	72	112	21	91 Alternate layers		....	V. large	....	Trace..	Trace
58	York............	..	....	..	40	20	20	....	....	V. large			
59	Knox............	..	....	..	59	12	45	2	....	Plentiful	....	Slight.	
60	Near Knox......	..	....	..	35	35	....	....	....	V. large			

The luxuriant growth of vegetation of all kinds on ground bordering coulees, lakes and ponds, bears testimony to the benefits which would be derived from the artificial application of well water. These effects are brought out by the following statements concerning the vegetation of this region compiled from a report made by Prof. M. A. Brannon, of the department of botany in the State University of North Dakota, who accompanied the writer in his field work.

The Devils lake basin contains the largest constant water supply of any corresponding area in North Dakota. This condition and the excellent soil of the region afford reasons for inferring that this portion of the state might have more timber than any other area of corresponding extent. Observation, however, does not show this to be the case for, on the contrary, the flora of this basin is notably lacking in woody plants. It is a treeless region, excepting for the narrow and incomplete timber border of Devils lake and Pleasant lake, isolated clumps of willows along coulee banks and a few timber claims. If conditions were ever otherwise there is no record of them. The prairie fires which swept these plains and swales for generations, and the small annual rainfall are believed to have prevented the distribution and development of trees. However, now that the fires are quite closely controlled, there is reason to expect the native groves to extend over larger territory and produce trees of considerable size. The timber claims which have been cared for bear testimony to the fact that trees can be grown successfully in this basin.

The native box elder (*Negundo aceroides*), elm (*Ulmus racemosa*), and white ash (*Fraxinus americana*) all make rapid growth when planted on timber claims that are properly cultivated and supplied with water from surface wells and coulees. Several species of poplar and willow are well adapted to the conditions found in most North Dakota tree claims. The principal native trees about Devils lake and Pleasant lake are burr oak (*Quercus macrocarpa*), rock elm (*Ulmus racemosa*), white ash (*Fraxinus americana*), hackberry (*Celtis occidentalis*), chokeberry (*Prunus virginiana*), and wild red cherry (*Prunus pennsylvanica*). There are numerous shrubs in addition to these, but none of them afford fuel or shelter. The largest trees are nearly two and one-half to three feet in diameter and from sixty to eighty feet tall. The water of Devils lake is slightly saline, but the border of the largest growth of trees extends almost to the shore line. From this fact one is led to believe that the water received through the subsoil is not injurious to the trees. There is ample evidence that excellent timber can be grown in this region if proper irrigation methods are employed. The native hardy varieties of trees need to be supplied with water only for a few seassons; later the young trees care for themselves. The hot winds which are so fatal to groves farther south, do not, as a rule, affect foliage in this state.

The presence of many valuable grasses in this basin indicates the adaptability of the soil for agricultural purposes. It is one of the best grain producing portions of the state west of the Red river valley. Wheat is the principal grain grown, and yields from twelve to forty-five bushels per acre depending on the season. No season is too wet for most of this rolling region, but many of them are too dry for large crops, which doubtless could be produced almost every year if a feasible method of irrigation were adopted. So far as observation of one year's conditions enable one to report, the effects of surface water are altogether favorable to the development of abundant straw and well filled heads. Barley, oats and rye are all grown in abundance.

The effect of surface water on the grain raised in the Devils lake basin is such that one is led to believe that irrigation would well repay the expense of constructing an economical system.

As elsewhere indicated, the land is admirably adapted to easy and effective watering by means of surface wells, coulees and shallow lakes. The cultivated vegetation which gave most ample testimony to the value of sufficient water supplies were vegetables and succulent garden plants, all of which are grown successfully in this region. In some truck patches which were supplied with irrigation ditches the water was obtained from creeks, or surface wells, and in all cases the plants were growing in a luxuriant fashion.

The same beneficial results from the use of surface water were observed in the cultivation of fruits, such as strawberries, blackberries, huckleberries, gooseberries, currants, plums and cherries, satisfactory yields being secured by artificial application of water during periods of drought. From the standpoint of the agriculturist, gardener and fruit grower, there is ample testimony to the fact that the water from surface wells, ponds, and artificial reservoirs is beneficial to vegetation. The only problem is how to secure this supply in critical periods of partial drought, which are liable to affect this region occasionally. With an economical and efficient system which could use this surface supply in such occasionally dry seasons, there could be guaranteed a degree of certainty in agricultural pursuits that would lead to the extensive development of a region exceedingly rich in soil and agricultural possibilities.

No estimate of the limit of the capacity of the surface wells in this part of the state can be given, since in but a few instances has there been any attempt to measure the flow per day or hour. In some cases data obtained when wells were dug or cleaned show a very rapid supply, reaching in one or more instances 40,000 gallons in twenty-four hours; such a supply is, however, certainly unusual. Ordinarily, as has already been stated, the inflow is rather slow owing to the compact nature of the containing material, and for this reason it might be necessary to tap the supply basin by several wells before a sufficient quantity of water could be stored to irrigate any considerable number of acres. On account of the short distance necessary to dig for water in most cases it would not be very expensive to put down several wells. Generally the farmer could, during seasons of little work, dig these wells himself, and they could all be connected by pipes or otherwise arranged to supply a common reservoir.

The water could be pumped by windmills or other convenient power. In North Dakota, where the days on which there is sufficient breeze to run a wind wheel are so numerous, this power should certainly be much more generally used than it now is, for pumping water and for other purposes, such as grinding feed, sawing wood, and operating various farming mills. In localities where all the conditions have been thoroughly studied and careful use made of windmill pumps, the general opinion seems to be that they can be successfully employed in irrigation. This subject has been discussed by Mr. H. M. Wilson, in paper No. 1 of U. S. Geological Survey water supply papers.

The prairie is gently rolling in this portion of North Dakota, and probably a considerable proportion of the land of the district described in this report could be watered at times when the rainfall was rather deficient at compartively small expense. For this purpose the high points should be selected for reservoir sites.

A suitable reservoir can be constructed easily by throwing up an earth embankment, which should be very thick and well lined with clay, asphaltum or cement. Each reservoir should be provided with one or more outlets which can be opened and cleaned readily, and should usually be supplied with water from several wells, the number depending upon the amount of water available from each and the acreage to be watered.

The best method of applying the water to the land depends upon the character of the soil, the degree of uniformity of the surface, the quantity of water available and the elevation of the reservoir, and each farmer must learn by actul experience what method is best adapted to his land and just how to operate his system. It may be said, in view of the characteristics of the land of this region, and especially on account of the elevation available for the reservoirs, that much less water will be required and less labor and skill in its application than in many nearly level districts where artificial and other modes of irrigation are practiced.

For much of this rolling land a method sometimes known as the catchwork system is probably most easily applicable. This consists in providing a number of distributing ditches which follow quite closely the contour of the ground having a very slight fall. These ditches are in a general way parallel to each other and at distances from three to four rods to ten rods or more, depending upon the slope of the surface. These nearly horizontal ditches are marked in figure 19, A B C. They are connected with other ditches

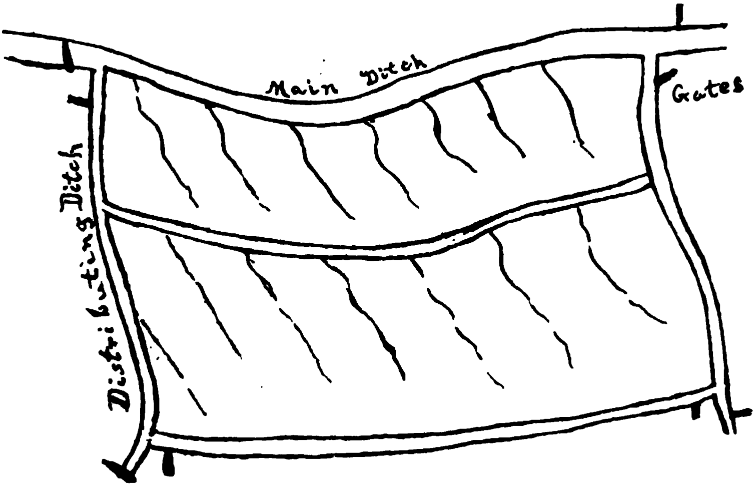
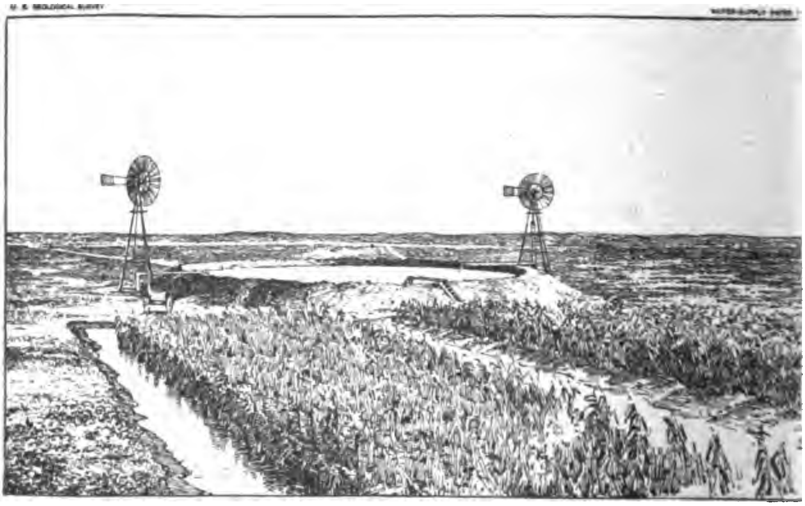


Fig. 19. Figure illustrating method of applying water on irregular ground.

marked L, which follow down the slope at as steep a grade as can be maintained without washing the soil. The lower side of each of the ditches A B C is made so nearly level that by placing a temporary dam or obstruction of earth at some point, for example in the ditch A, the water will be forced to overflow and spread uniformly down the slope, being caught in turn by the next ditch, B, below. The flow in this lower ditch can be increased by the quantity turned down the side hill ditches, L, and these in turn overflowing spread over the slope to the next intercepting ditch, C, below.

Where the ground is so irregular that the water will not spread evenly over the strip of land below the ditch A, it is often desirable to run shallow furrows (f) diagonally down the hill slope, stopping these before they reach the lower ditch, B. By making these at the proper grade, and by regulating the flow by means of small obstructions made with a shovelful of earth, it is possible to give the field a uniform soaking.

Because of the remarkable fertlity of the soil of this district, and the fact that this well system is to be used only as a supplement for a short period in the year and not at all in some years, no one should be led to underestimate the value that would be derived from such a system properly managed. The fact that irrigation is not a necessity makes it seem to many not worth the trouble unless from eighty to 160 acres of land can be watered from the start. This idea is certainly wrong. Irrigation is in



WINDMILLS AND CIRCULAR RESERVOIR

Fig. 20. Windmills and irrigation on the plains.

nearly all cases a great and lasting aid only in those sections where work is begun on a small scale and where the most careful efforts for improvement are made. Those who attempt to apply water artificially in this section should be content to begin with from five to twenty acres, and not endeavor to water large tracts until they have carefully determined the best way to construct the plants and to use the water.

SANITARY CONDITIONS OF THE WATER

One of the most important matters for consideration in connection with the water used by any community is its sanitary condition.

*Comparatively few people have a proper conception of the means of providing a pure water supply or of the way to retain its purity; nor do many thoroughly realize what great danger lies in the use of impure water. It is with the hope of directing attention to the great desirability of improvement in the sanitary conditions of wells used for domestic purposes that the few words following are added.

In this district almost the entire supply of water for domestic use is derived from open wells, about three or four feet in diameter and usually from twenty to fifty feet deep. The water is generally found in a sand and gravel stratum, confined by impervious beds of clay, the lower of which usually forms the bed of the common subterranean level of the region. A water supply derived from a source thus protected by nature from surface contamination is nevertheless liable to become dangerous to health unless more than common care is exercised in the location and construction of the well. A large percentage of the wells visited by the writer were found to be improperly located. For convenience in supplying water for cattle many are in stables or in or near the edge of stock yards, others are on low ground or on some hillside where the drainage from above tends to soak into the well. Under such conditions it is the greatest wonder that cases of fever and other diseases are not of more frequent occurrence.

In the country there is no necessity for placing a well in such a position that there will be danger from surface contamination. There is an abundance of space and water is easily obtained almost anywhere.

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*W. J. McGee, The Portable Waters of Eastern United States; Fourteenth Annual Report. U. S. Geol. Survey, Part II.

Special precaution should be used to make tight the top and sides of the well, so that the water will filter through as great a thickness of material as possible before finding its way into the well. This condition can be secured by laying up a brick or stone wall in hydraulic cement from near the bottom of the well to about a foot above the surface. Care should be taken that any open space between the sides of the well and the brick wall is filled at the bottom with cement and sand or clay, and that it is carefully covered at the top with heavy boards and otherwise made tight. Apparent cleanliness and purity should not be assumed to guarantee absolute freedom from contamination.

The location and surroundings of a well must always be looked after. Very frequently disease germs lurk unsuspected in what is seemingly to the eye the clearest and purest water. The writer regrets that he cannot here give a large number of analyses to show the organic matter in water from wells of different locations, but it was almost impossible, owing to the conditions under which the work was carried on, to make the organic determinations, even in those wells which were given an approximate mineral analysis, since search for organic matter must be made very promptly after the collection of the samples, which was impossible in these cases. However, the mineral analyses were made and careful observations were taken regarding the location, elevation and various surrounding conditions, and the effects of these conditions may be seen in a way by reference to the following table of analyses. An examination of these analyses and of the record of the field tests shows that in a very large proportion of cases the water obtained from wells located on low lands is poorer than that from those on high lands. In most cases where there had been sickness, caused possibly by the water, the wells used were situated in low places or near stables or cesspools.

Table showing salts and mineral matter in water of wells at different elevations:

Name	Grains Per Gallon				Location
	(1) Chlorine	(2) Hardness	(3) Carbonates	Total Solids	
1 Wilcox	0.49	18.	4.24	......	Good, high
2 Lindeberger	1.32	19.	6.36	37.9	Good, very high
3 Cocking	0.49	17.	8.48	87.8	Good, very high
4 Goldberg	4.12	44.	4.24	78.3	High
5 Johnson	5.44	23.	29.68	98.9	Too near stock yards, high
6 Wood	3.63	21.	12.72	40.3	Medium
7 Falgeson	4.12	7.5	25.44	81.2	Medium
8 Enger	4.61	54.5	19.08	149.6	Medium
9 Maristeau	9.39	42.	6.36	117.	In barn, low
10 Jacobson	14.67	79.	23.32	231.	Near barn, low

(1) Estimated as equivalent to sodium chloride.
(2) Equivalent to carbonates and sulphates of lime and magnesia.
(3) Lime, magnesia and alkalias estimated as equivalent to sodium carbonate. With the true alkalias was estimated all, or a part of the carbonate of lime and magnesia.

The number of wells located near barnyards and supplying water for household purposes was astonishing. Were it not for the remarkably healthful climate and for the out-of-door occupation and good resisting power of those habitually using such water there would be a larger amount of sickness. Water obtained from wells in low places and where the water rests in blue clay was nearly always found to be stronger in alkalies, salts and sulphuretted hydrogen or soluble sulphides and of inferior quality to that from wells located on higher sand or gravel ridges. Very few of the wells of this district are walled up with brick or stone. Wooden planks are generally used, simply to keep the well from caving in. Some wells are not even planked up. The top is usually very poorly covered and many are kept quite open.

It must not be understood from the above statements that the water of this region is naturally dangerous, for this is not the case. There is, however, great room for improvement in sanitary conditions within the control of man. The following points are suggested as possible aids in bringing about an improvement in the quality of water used for household purposes in this region:

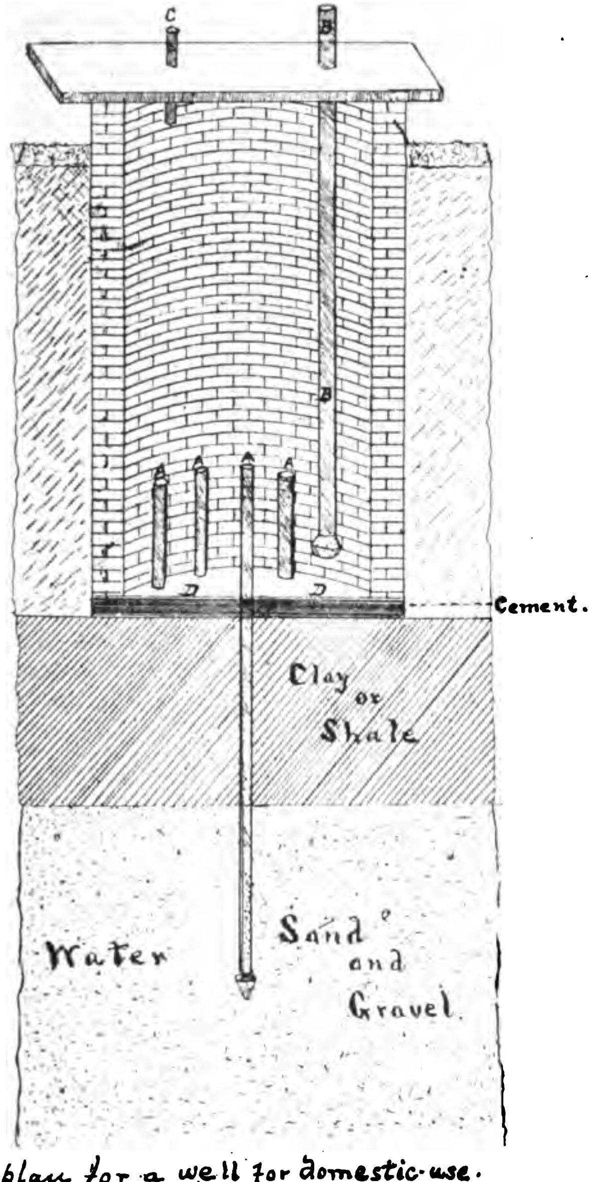
Locate the well on high land, and whenever possible let it be in a sand ridge, or at least in a location which there is reason to believe is underlain with such material. This will not be very difficult to accomplish in the case of most of the wells in this district. Investigation goes to show beyond a doubt that in most cases the best water is obtained when the well is put through much sand and gravel, at least for a portion of its depth. This fact of course, is generally recognized. Sand and gravel act as a filtering bed, and are often used for the improvement of otherwise impure supplies. Many cities use sand filtering beds with remarkably good results. In the east one of the most thoroughly tested systems of this kind is the comparatively simple sand bed arrangement of the city of Lawrence, Mass., by which the water is purified for domestic use. In North Dakota a similar system is used at Grand Forks with gratifying results. Usually the organic impurities in the water after filtration amount to but a small fraction of that found in the unfiltered water. Wherever water is found which passes through layers of sand and gravel, as is commonly the case in this part of the state, it will have been subjected to a natural filtration which, as the analyses given in this report show, results in a marked improvement in its quality.

Wells should be located on high land to prevent contamination from the slow percolation of impure surface water; wells in low places naturally receive the sewage and general drainage from the higher portions of land; but high and rolling land favors a rapid run-off of surface water, and so usually prevents the introduction of surface impurities.

For obvious reasons it is imperative that wells to supply drinking water should not be stopped at too shallow a depth. Many wells may be found which are little more than mere basins dug a few feet in the soil and subsoil. The water thus obtained is all from the immediate surface and is very liable to contamination. Wells dug for domestic use should be walled up with brick or stone and not with wood, since the latter does not keep out surface water but furnishes favorable conditions for the accumulation and growth of organic matter; the wood soon begins to decay, thus supplying impurity, while the cracks and rotten places in the wood allow access to small animals.

Based upon the principles mentioned, there are many ways of constructing wells which will furnish pure water and be entirely satisfactory.

The accompanying illustration, figure 21, is given as a suggestion of one safe method of construction. This will be found applicable in many places in this region, but will need to be modi-



A plan for a well for domestic use.

Fig. 21. Plan for a well for domestic use.

fied oftentimes to meet the local conditions. This plan is intended only for localities where the water will rise by its own pressure at the lowest stages to a point above the top of the inflow pipes marked A, in figure 21. Wherever the water does not rise of its own pressure so as to overflow these inlet pipes this design for a well would not be available, as the pump could only lift the water out of the well when it rises above the intake pipe to the pump. The well is dug to within a few feet of the sand which contains the water and which is capped by compact clay or shale. Through this clay or shale the iron tubes, A, are driven, or, if the shale or clay is too hard the tubes are placed in holes drilled through. All of these tubes, six or eight in number, pass into the water-bearing sand, as seen by the central tube. Each tube is provided with an ordinary pointed cap for the lower end and is perforated along the sides for some distance. The bottom of the well is then cemented very carefully around the pipes, and the entire bottom, D, is covered with a thickness of about a foot with a fine concrete made of Portland or other good hydraulic cement. Upon this the brick wall is laid in hydraulic cement mortar to about one foot above the surface, and is provided with a tight fitting cover. The tube, C, is placed in the cover to allow a free circulation of air. It should be provided with a fine screen on top or a perforated cap and sides. The tube, B, ending in a perforated cap, is the suction tube leading to the pump. A well constructed in this manner is a great improvement over the one of common construction, since it permits no foreign matter to enter the well and does not require that the water shall stand in the blue clay or shale and thus increase the amount of alkalies as well as of other mineral matter. Whenever it is desired to clean the well, the tops of the tubes, A, can be plugged up and the water drawn out. When there is doubt about the water rising, at its lowest stage, to a sufficient height above the inflow pipes, A, to insure a good supply, some slight modifications may be adopted. For example, the bottom of the well should be carried down very near to the water-bearing stratum. When it is evident that the water will rise some distance above the bottom one large intake pipe, A, or several smaller ones, may be put down well into the water-bearing stratum. The concrete can then be placed above these in the way illustrated or the pump may be connected directly by means of pipe B to the one or more pipes sunken into the water-bearing stratum, and then the concrete can be placed around these pipes. In this case water will be gotten as long as the supply keeps up in the carrying stratum. The cylinder of the pump should not be located too far above the water supply.

When it is not necessary to dig very far for water, a better plan still would be to extend the open well, curbed with brick laid in cement mortar, down to a point say from four to eight feet below the water line, provided the water-bearing stratum is that thick. In this way the bottom of the well will remain directly in the sand or gravel carrying water. The bottom is not cemented in such a case. The pipes connecting with the pump are then run directly nearly to the bottom of the well. It should terminate in a large screen resting upon a stone of good size or a little pier of brick. The stone or pier and the screen of the intake pipe should now be covered with gravel. If desired, a little coarse charcoal of the best kind may be mixed with the gravel. It is well then to cover the charcoal with small gravel and finally with coarse sand This will produce a very excellent filter bed. It is important to have a good screen at the bottom of the pump pipe. This may be made from a large core or bulb with openings on the sides and bottom and covered with rather fine antirust wire screen. It is desirable generally to use a screen which confines its surface to within six or eight inches of the bottom. This will permit the withdrawing of nearly all the water before the pump takes air. Such care or expense need not be taken with wells for stock or irrigation, but simply with those which are employed for household purposes.

In wells used for domestic purposes it is highly desirable that a large amount of water be removed, for this is an important aid in keeping the supply pure and preventing the accumulation of alkalies or other salts. In nearly all cases in this region the greater quantity of water drawn the better its quality. Where windmills are used and a large amount of water is pumped out, the improvement is noticeable. The value derived from the removal of a large quantity of water is probably not only due to the prevention of the accumulation of alkalies and other salts, but also the prevention of certain chemical changes which soon take place in the standing water. One of the most noticeable of these is between the alkaline carbonates and sulphides, mostly of iron, which in the presence of a small amount of organic matter probably combine so as to form traces of carbonate of iron and set free a small amount of hydrogen sulphide, which gives the offensive odor to many wells in which water is allowed to stand, especially if it is confined in shale. When large quantities of water are used, so that the supply is constantly being changed, there is not much opportunity for such chemical decomposition.

There is little doubt that the proper construction of the wells and the removal of large quantities of water will greatly improve the quality of the supply. The containing shales and clays will doubtless be slowly relieved, by this process of washing, of much of their impurities. More care should certainly be given to the sanitary conditions of drinking water in this region. Few subjects need more attention or are more worthy of thought than this one of domestic water supply. Upon it to a great extent depends the health, comfort and prosperity of the whole community.

LAWS GOVERNING COAL LAND ENTRIES

While engaged in field work during the past summer, questions were so often asked in regard to coal land entries that it has seemed wise to reproduce those portions of the United States statutes touching these points, which give the essential conditions under which such entries can be made:

COAL LAND LAW

SECTION 2347. Every person above the age of twenty-one years, who is a citizen of the United States, or who has declared his intention to become such or any association of persons severally qualified as above, shall, upon application to the register of the proper land office, have the right to enter by legal subdivision any quantity of vacant coal lands of the United States not otherwise appropriated or reserved by competent authority, not exceeding one hundred and sixty acres to such individual persons or three hundred and twenty acres to such association, upon payment to the receiver of not less than ten dollars per acre for such lands, where the same shall be situated more than fifteen miles from any complete railroad, and not less than twenty dollars per acre for such lands as shall be within fifteen miles of such road.

SEC. 2348. Any person or association of persons severally qualified, as above provided, who have opened and improved, or shall hereafter open and improve any coal mine or mines upon public lands, and shall be in actual possession of the same, shall be entitled to a preference right of entry, under the preceding section, of the mine so opened and improved; provided, that when any association of not less than four persons, severally qualified as above provided, shall have expended not less than five thousand dollars in working and improving any such mine or mines, such association may enter not exceeding six hundred and forty acres, including such mining improvements. * * *

SEC. 2350. The three preceding sections shall be held to authorize only one entry by the same person or association of persons; and no association of persons any member of which shall have taken the benefit of such section, either as an individual or as a member of any other association, shall enter or hold any other lands under the provision thereof; and no member of any other association which shall have taken the benefit of such sections shall enter or hold any other lands under their provision; and all persons claiming under section twenty-three hundred and forty-eight shall be required to prove their respective rights and pay for the land filed upon within one year from the time prescribed for filing their respective claims; and upon failure to file the proper notice, or to pay for the land within the required period, the same shall be subject to entry by any other qualified applicant.

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THIRD BIENNIAL REPORT

OF THE

State Geological Survey of North Dakota

A. G. LEONARD, Ph. D.
State Geologist.

BISMARCK, 1904.

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ADMINISTRATIVE REPORTS

ADMINISTRATIVE REPORTS

UNIVERSITY OF IOWA,
IOWA CITY, May 6, 1904.

To the Trustees of the State University of North Dakota:

GENTLEMEN: I submit herewith the results of field work carried out under my direction during the summer of 1903. In accordance with the purpose stated in my report to you in 1901, the geological work undertaken by the Survey has been practical in its nature, aiming to bring out the undeveloped natural resources of the state. Co-operating with the United States Geological Survey, the possibility of irrigating considerable tracts along the Missouri and its tributaries with pumping engines which use lignite as fuel has been carefully studied with results that seem most encouraging. A report with recommendations was submitted to the hydrographic branch of the United States Geological Survey, portions of which will appear in the Second Annual Report of the Reclamation Service.

Mr. L. H. Wood, of the University of Chicago, continued to serve as assistant geologist. Messrs. Hinds, Holgate, Goodall and Pease, students of the University, served efficiently as field assistants. Mr. Wood with two assistants started at Medora and descended the Little Missouri to its mouth. Meeting my party, which had come down the Missouri in a small boat from the Montana line, a conference was held at Mannhaven. Here Mr. Woods' party fitted out by wagon for a trip up the Knife river, while my party continued its studies down the Missouri to the mouth of the Cannon Ball. From this point the valley of the Cannon Ball was followed by wagon to Wade. Here the river forks, and the party chose to follow the Cedar or South Fork of the Cannon Ball to the end of the Standing Rock Indian Reservation. Returning, observations were made along the Upper Heart river. Separate reports of the work of the two parties are submitted herewith.

At the end of the summer of 1903 I was obliged to resign the position of State Geologist of North Dakota, on account of removal from the state. Dr. A. G. Leonard, whom you have chosen as my successor, enjoys the confidence of geologists throughout the country, and to his care future geological studies in North Dakota may safely be entrusted.

Respectfully submitted,
FRANK A. WILDER.

UNIVERSITY OF NORTH DAKOTA,
GRAND FORKS, October 8, 1904.

Hon. George E. Towle, President Board of Trustees of the University of North Dakota:

DEAR SIR: I have the honor to submit herewith the following report on the work of the State Geological Survey of North Dakota during the past two years. During the first half of this period the Survey was under the direction of Dr. Frank A. Wilder, whose report on the field work for the summer of 1903 is appended.

During the past year the second edition of the Second Biennial Report, dealing with the lignite deposits of the state, was issued. The demand for the report was so great that the first edition of 1,500 copies was exhausted within a few months and the Legislature authorized a second of 2,500 copies.

The frequent requests for the reports of the Geological Survey come not only from within the state but from individuals and companies all over the country. They indicate a widespread interest in the natural resources of North Dakota, and it is an important function of the Survey to furnish information concerning these resources. The answering of the numerous letters of inquiry which come to the office takes no small share of the time of the State Geologist.

The policy of the Survey in the future, as it has been in the past, will be to emphasize the economic problems presented for investigation and to do everything in its power to develop the natural resources of the state. This should in fact be the chief aim of any geological survey. In carrying out this purpose the Survey has issued a report on the topography, geology and natural resources of North Dakota; a second dealing largely with the lignite coal fields of the region, and the forthcoming Third Biennial Report will contain the results of extended investigations as to the possibility of irrigating large tracts along the Missouri and its tributaries with pumping engines, using lignite as fuel.

The summer's work of the State Geologist was directed in part toward becoming familiar with the different geological formations which occur within the state. For this purpose I visited a large number of widely separated localities where these formations appear at the surface, and the character of the rocks was carefully studied. At the same time I began the investigation of the clays, which will form the subject of the report to follow the one now in press. These have already been studied by Professor Babcock and a large amount of valuable information secured, but much is left to be done before a full report on them is published. The many excellent clays which are found in all portions of the state were examined. Detailed sections were made showing the alternation and succession of the beds, with their thickness, and these will form the basis necessary for future study. Nearly all the clay plants were visited and much valuable information concerning them secured. The brick yards and coal mines in the vicinity of Williston, Minot, Burlington and Kenmare were visited. The Laramie beds, which are so rich in seams of lignite and valuable clay deposits, were carefully studied near Medora, Sentinel Butte, Dickinson, Coal Harbor and many other points in the western part of the state. The high grade fire clays, pottery clays and brick clays at Dickinson were found to have quite a wide distribution. They outcrop in the vicinity of Gladstone and extend east of there for a considerable distance, while they are found at least several miles to the north and south of Dickinson. It is hoped that next summer sufficient work can be done on these white, high grade clays to determine their distribution, thickness and stratigraphic relationships. Other clays of good quality were observed near Jamestown and Valley City, where the Pierre shales outcrop along the James and Sheyenne rivers.

The value and possibilities of our clays are strikingly shown in the North Dakota exhibit in the Mines Building at the St. Louis World's Fair, where a great variety of beautiful and artistic pottery is displayed, all manufactured experimentally in eastern factories from the clays found near Dickinson and elsewhere in the state.

Some time was spent in the Turtle Mountain region in the endeavor to find whether lignite occurs there. Coal has for years been mined near the eastern and northern edge of the mountains, in Canada, and also near Dunseith, in Rolette county. The drift deposits are so thick in this district that the underlying coal-bearing beds of the Laramie formation do not outcrop, but good-sized fragments of the coal are found imbedded in the drift clays near Bottineau and elsewhere in the mountains, and furnish evidence that beds of coal are not far distant. It is very probable that seams of lignite will be found at no great depth below the surface, and the expense of putting down some prospect holes to determine their depth and extent would not be great, and would be warranted by the benefits secured if coal were discovered in this vicinity.

In connection with other lines of investigation, the building stones received some attention. Those near Velva, Sentinel Butte, Dickinson and elsewhere were examined and found to have the necessary durability and to be readily quarried. These sandstones form beds extensive enough to furnish an abundance of building stone of good quality. Three or four buildings in Velva have been constructed of the rock. At present about the only building stone throughout a large part of the state is supplied by the granite and other boulders of the drift, brought in from the north by the great glaciers which once covered this region.

A trip was made to the Pembina Mountains for the purpose of studying the rare and valuable cement rock and brick clays of that area.

The Third Biennial Report, which is now in the hands of the printer, contains reports on the following subjects:

(1) The Lignite on the Missouri, Heart and Cannon Ball Rivers and Its Relation to Irrigation.

(2) Report on the Region Between the Northern Pacific Railroad and Missouri River. Its Topography, Climate, Vegetation, Irrigation Possibilities and Coal Deposits.

(3) The Results of Stream Measurements in North Dakota During the Past Two Years.

(4) The Geological Formations of North Dakota.

It is believed that the volume contains much information of a very practical nature on the lignite deposits and irrigation problems, and will serve to interest and educate the citizens of the state in the needs and possibilities of irrigation in the western portion. The maps accompanying the report show the location and thickness of the lignite seams outcropping along the chief streams, the location of the larger river flats and other interesting features of the country.

The earliest investigations in the state on the possibility of using lignite for fuel in pumping the waters of the streams up onto the adjoining river flats were carried on by the State Geological Survey under the direction of Dr. F. A. Wilder. Work on this problem was begun in the summer of 1902 and continued during the next season by two parties who followed the Missouri and its tributaries. It is gratifying to be able to report that this line of investigation has now been taken up by the reclamation division of the United States Geological Survey. The Federal Survey now has two surveying parties at work along the Missouri, one in the vicinity of Bismarck and another below Williston, studying the river flats and the possibility of irrigating them by pumping from the stream, using the lignite close by for fuel. If a favorable location can be found, the Government may establish an experimental pumping plant.

Through Professor Chandler the State Geological Survey is co-operating with the United States Geological Survey in measuring the flow of all the principal streams of North Dakota, and the results of these measurements are given in the present volume. They will be found of much value in the investigation of the irrigation possibilities of the different drainage areas.

It is greatly to be hoped that the appropriation at the disposal of the Survey during the next two years will be sufficient to make it possible to co-operate with the United States Geological Survey in the preparation of topographic maps of areas in the state. Such maps would be of the greatest service in the study of irrigation problems, and a good topographic map is necessary before geological mapping can be undertaken. As soon as the required topographic sheets have been completed the Survey will begin mapping the formations of economic importance in the western part of the state, in co-operation with the Federal Survey.

The Survey has already made considerable progress in its investigations of the valuable clay deposits of the state, and this work is being pushed to completion as fast as possible. The results will be embodied in the next report, which will contain a full discussion of the chemical and physical properties of clays, the manufacture of the various clay products, and the geological character and distribution of the North Dakota clays. The Survey also plans to take up the study of building stone, cement rock and other subjects, and to continue the investigation of the lignite deposits, upon which there is still much to be done. Certain restricted areas, such as single counties, will be selected for careful study and detailed mapping, reports being prepared on the topography, geology and economic resources of the areas, including their water supply and irrigation problems.

The Survey is building up a valuable library through the exchanges received in return for its reports. Many volumes of reports from the Federal and State Geological Surveys are received, and also the publications of American and foreign scientific societies. The best mining and geological journals are also received in exchange.

Respectfully submitted,
A. G. LEONARD,
State Geologist.

THE LIGNITE ON THE MISSOURI, HEART AND CANNON BALL RIVERS AND ITS RELATION TO IRRIGATION

BY FRANK A. WILDER

INTRODUCTION

Opportunities to irrigate in a large way in North Dakota, for the present at least, seem to be confined to the broad terraces, or benches as they are locally called, along the Missouri and its tributaries. These streams are deeply intrenched and it does not seem possible, by any means now available, to raise water from them over the bluffs that rather sharply bound the broad valleys, a vertical distance of from 150 to 400 feet, and irrigate the upland.

Where the Yellowstone enters the state, it has a fall of only 2.7 feet per mile, while the Missouri's gradient for an equal distance is about two feet. A fall of a foot per mile is necessary to carry water in an irrigating ditch, so that to raise water forty feet from the Missouri would require a ditch forty miles long. The tributaries of the Missouri have gradients somewhat higher, but the flats along them are cut up by the meanderings of the streams, and conditions are not favorable for long lateral ditches or extensive reservoirs.

In view of the fertile terraces in the valleys of the streams themselves ranging in elevation from fifteen to 100 feet and the abundance of lignite along them, it seemed desirable to consider the possibility of irrigating the 250,000 or more acres included in the stream terraces, by pumping from the streams directly, using lignite as fuel. Co-operating with the Department of Hydrography of the United States Geological Survey, therefore, the lignite area has been studied, and practical tests have been made to determine the value of the lignite as fuel in generating steam. With these determinations as a basis computations have been made to determine, at least in a rough way, the cost of irrigating river flats whose elevation is less than 100 feet.

While engaged in these practical studies, opportunity was given to consider a number of important scientific questions, and brief notes covering the points noted, are given in the closing paragraphs of the accompanying reports.

The brief statement of the facts in regard to the nature and extent of the lignite given below is taken from the more extended report of two years ago.*

EXTENT OF THE LIGNITE AREA IN NORTH DAKOTA

While thin beds of lignite have been recognized in the eastern part of the state and have been described† at the southern bend of the Sheyenne river, in Township 135, Range 54, Section 32, which lies about twenty-five miles southeast of Valley City, workable seams have not been found, except in the Turtle mountains, till the center of the state is reached. The plateau known as the Turtle mountains is an outlier of the lignite area proper, which may be roughly bounded on the east by a line beginning at the northern boundry of the state, and thirty miles east of the Minneapolis, St. Paul & Sault Ste. Marie railroad, and extending southeast to Harvey, thence south through Steele to the southern boundary. This line is shown in plate 1. More minute study, aided by well borings which will doubtless be made as the country is settled, will probably shift this line east or west at certain points thirty or forty miles. The state lines are its boundaries on the north, south and west, while outside the state the lignite continues in these three directions. Only this region, in which workable beds of lignite may reasonably be looked for, is included in this report under the term "lignite area." Even when so restricted it is of very great extent, equal to at least half of the state of Ohio.

It is highly probable that lignite does not exist in beds of workable thickness in every part of this region, but it is equally probable that the fraction of the area lacking lignite in beds of three or more feet in thickness is a small one, not more than one-fifth of the whole. In the southeastern portion of the area, about the lower part of the Cannon Ball river, thick beds seem to be lacking. Where heavy beds are present, all may not be available, either on account of depth or some difficulty in mining, and throughout the eastern portion of the region they are so thoroughly concealed by glacial drift that, without a knowledge of the underlying formations and of the surrounding country, their existence would be unsuspected.

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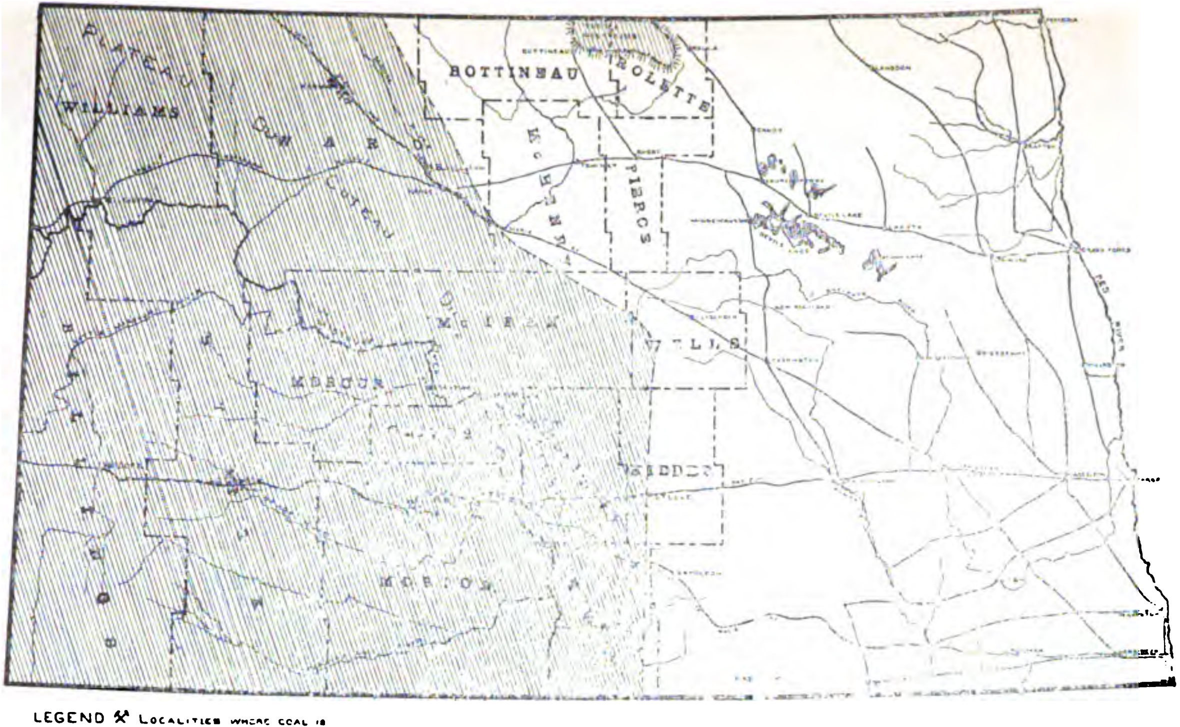
*Second Biennial Report of the North Dakota Geological Survey.

†Upham in Monograph XXV, page 92, United States Geological Survey.



A map showing approximately the area in which lignite occurs in quantities sufficient to be of economic importance. The lignite area is marked by diagonal lines,

UNIV. OF MICH.

STRATIGRAPHY

General Relationships of Strata.—The restriction of the term "lignite area" to the area in which workable beds of lignite are found, greatly simplifies the stratigraphic series and limits this paragraph to a consideration of the Laramie and the glacial drift.

The Laramie.—This, the latest stage of the Cretaceous, contains all of the workable lignite in North Dakota. Early students of the field referred part of the lignite beds to the Fort Union on paleontological grounds. Reasons for retaining the distinction have not seemed adequate and the effort may well be dropped. The Laramie is found over the region previously outlined as the lignite area, though its eastern border is buried, often deeply, by glacial drift. The difference in elevation of deposits of this stage, actually exposed within the state, is at least 1,400 feet. Its greatest thickness, safely shown by the well at Medora to be more than 2,000 feet, occurs in the western part of the state, its vertical extent gradually decreasing toward the east, till at the edge of the Coteau du Missouri it drops off sharply, beyond which it continues as a relatively thin series. The Laramie formations consist of clays, sands, sandstone, lignite, and thin bands of hematite, clay-ironstone and shaly limestone.

Nature of the Lignite Beds.—The numerous natural exposures of lignite in the driftless area, and the remarkably fine opportunities to study the Laramie strata given by the Bad Lands, make it possible to draw, even from a preliminary study of the region, rather far reaching conclusions in regard to the nature of the lignite beds.

Number of Beds in Single Vertical Sections.—Five well developed beds outcrop in the bluffs of the Little Missouri at Medora, and may be traced for miles both north and south of this point. Along the Missouri south of Williston five and six beds show in a single section, and can be traced for long distances, while on the Fort Berthold reservation nine well developed beds occur in a single exposure. The wells at Medora and Dickinson show an even greater number of beds. Near the eastern edge of the lignite area the number of beds is greatly reduced, but even here two and three exist at certain points, though generally but one is workable.

On account of the nature of the beds, considered in a later paragraph, their number does not remain constant through large areas, and it is possible, though hardly probable, that in a few localities in the heart of the lignite area a prospect hole passing completely through the Laramie would not encounter a single lignite bed. This variation in number and thickness of seams, often within comparatively short distances, will be a factor of great practical importance in opening up on a large scale a new lignite field. In the first place, it will increase the number of prospect holes that must be sunk to determine the amount of available coal in a given area. To offset this, however, are a number of conditions which make prospecting unusually easy.

Thickness of the Beds.—The lignite beds in North Dakota vary in thickness from an inch to forty feet. This maximum thickness, which was carefully measured in the summer of 1902, outcrops in Township 135, Range 101, Section 31, and will be described in connection with the lignite on the Little Missouri river. Three beds which reach a thickness of twenty-five feet are known, while beds fifteen feet thick are not uncommon. In the western part of the state beds two and three feet thick are so common that in this report it is not practical to note them minutely.

Extent of Beds.—As important from an economic point of view as their thickness is their persistence laterally. Attention was directed to this point, and the elevation of beds was noted in order to correlate if possible the beds exposed at one point with those at another. Generally such a correlation was impossible for points distant from each other a number of miles on account of variations in thickness and elevation. While a single bed was often traced for five or six miles along the banks of the Little Missouri, others seen at the same time thinned out and gave place to others above or below them. The interrupted bed might begin again farther on after a break of half a mile or more, the lignite in the interim being replaced by a bituminous or nearly pure clay. The deduction, which early in the work seemed true, that certain horizons in the Laramie are much richer in lignite than others, was not borne out by later observations. For a given locality the statement holds good, but an elevation which abounds in lignite at one point may be barren in another. A striking instance of the rapid thinning of a bed is given by the forty-foot bed already referred to, which within one-fourth of a mile shrinks to seventeen feet, the top and bottom drawing together like the surfaces of a lens. Sufficient work has been done at one point near Minot to demonstrate the persistence of a thick bed beneath the greater part of a township, but this seems to be the exception rather than the rule. Darton attempted to correlate the beds encountered in the wells at Medora and Dickinson, the distance between the points being thirty-nine miles, but in view of the data gathered for this report the attempt seems hardly practical.

Variations in Fuel Value of Lignite in a Given Bed.—A majority of the beds examined and tested show no great difference in fuel value from top to bottom. In some instances, however, the differences in the composition of the lignite in a given bed was considerable. Not infrequently the upper foot or two are inferior, and are left for roof in mining. The loss in this case is not as great as might be expected, for it is often more economical to leave coal for a roof than to timber. When the lignite lies directly under the glacial drift, as at the Hanchett mine ten miles southwest of Velva, the upper portion shows deterioration. Shaly layers sometimes occur, which if mixed with the coal from the rest of the bed, bring up the percentage of ash for the whole very considerably. Sulphur in any form is present commonly only in traces. Iron nodules, which prove so annoying to the operator of mining machines in the east, do not occur in the lignite, and there are no hindrances to the use of drills and undercutting machinery.

Variations in Fuel Value of Different Beds.—The chemical analyses of seventy samples from as many beds, given in a later chapter, throw light on the fuel value of lignites from as many parts of the state. Samples were not taken from beds that were obviously too thin or to impure to be of economic value, but on the other hand, all analyses made are given, whether favorable to the lignite or not. The lignites taken as a whole will probably average better than the samples analized indicate, for in many cases fresh material could not be obtained and the weathering on the surface of a natural exposure is sufficient to lessen the carbon values for some feet from the surface. In the discussion which follows lignites which are reported as good have not more than 8 per cent of ash and fixed carbon between 40 per cent and 50 per cent.

Possibilities of Bituminous Coal Existing at Greater Depths.—There are no theoretical considerations to support the rather common notion that at greater depths a higher grade of coal exists. The analyses of the coals found by the railroads in the deep drillings undertaken in the western part of the state have not been examined. But this work was done some years ago, and since no development work has followed it the inference seems fair that bituminous coal in significant quantities was not found.

A Popular Fallacy in Connection with the Lignite.—The belief so often expressed, that lignite beds outcropping on erosion slopes are certain to thicken as the mine goes back into the hill, is hard to account for except in the optimism which fortunately is an endowment of a large part of our race. While in many cases the beds doubtless thicken away from the outcrop, the reverse will as ofton prove true. The lignite beds being in general lens-like, it is impossible without drilling to determine whether the outcrop represents a section near the edge of the lens or across the center. In the former case the lignite will thicken as the drift goes into the hill or bank till the center of the lens is reached, while in the latter it will become thinner.

Summary of Boiler Tests.—Careful evaporative tests with North Dakota lignite have been made, which are given at length elsewhere.* These experiments, undertaken at the Asylum for Insane at Jamestown, Missouri Valley Milling Co. at Mandan, Fargo Edison Electric Co. at Fargo, the State University at Grand Forks and the State Agricultural College at Fargo, plainly show that a pound of lignite will evaporate 4.1 pounds of water under ordinary boilers. With these figures as a basis, it is possible to determine the economy resulting from the use of lignite when competing with other fuels in any part of the state.

PUMPING WATER FOR IRRIGATION, USING LIGNITE AS FUEL

The computations here given, which indicate the amount of lignite that will be required to raise water to the level of the various flats found on the streams in western North Dakota, have been made by Charles S. Magowan, Professor of Municipal and Sanitary Engineering at the State University of Iowa. He accompanies the computations given in the table with the following statements.

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*Second Biennial Report, North Dakota Geological Survey.

The first question that presents itself is that of the duty on water. In the absence of definite data on this point from North Dakota, it is necessary, to rely on the results of irrigators who have worked under somewhat similar conditions. Wilson* records that in Montana about eighty acres are served per second foot of water supplied, and that if from fifteen to eighteen inches in depth be furnished during an irrigating season, it is believed to be sufficient. Mr. Wilson makes the general statement that 1,000 gallons per minute will irrigate from five to ten acres per day, and in the course of a season about 100 acres.

If water is supplied to a ten-acre tract at the rate of 1,000 gallons per minute for twenty-four hours, the depth of the water over the whole tract will be 5.58 inches. If water to this depth applied five times during the irrigating season is sufficient, a plant of this capacity should care for 200 acres.

This statement is made because it is desired to use 1,000 galgons per minute and multiples thereof in discussing pump efficiencies.

Centrifugal pumps only are discussed, since it is believed that, in view of the recent improvements that have been made in their construction, no other pump can so economically handle large quantities of water under the given conditions, even for the higher lifts. The discussion is based on belt driven centrifugal pumps, though some reference will be made to steam centrifugal pumping engines; that is to machines where engine and pump are direct-connected, being built on the same base.

The evaporative power of the lignite is taken as 4.1 pounds of water per pound of coal as shown by test quoted elsewhere.†

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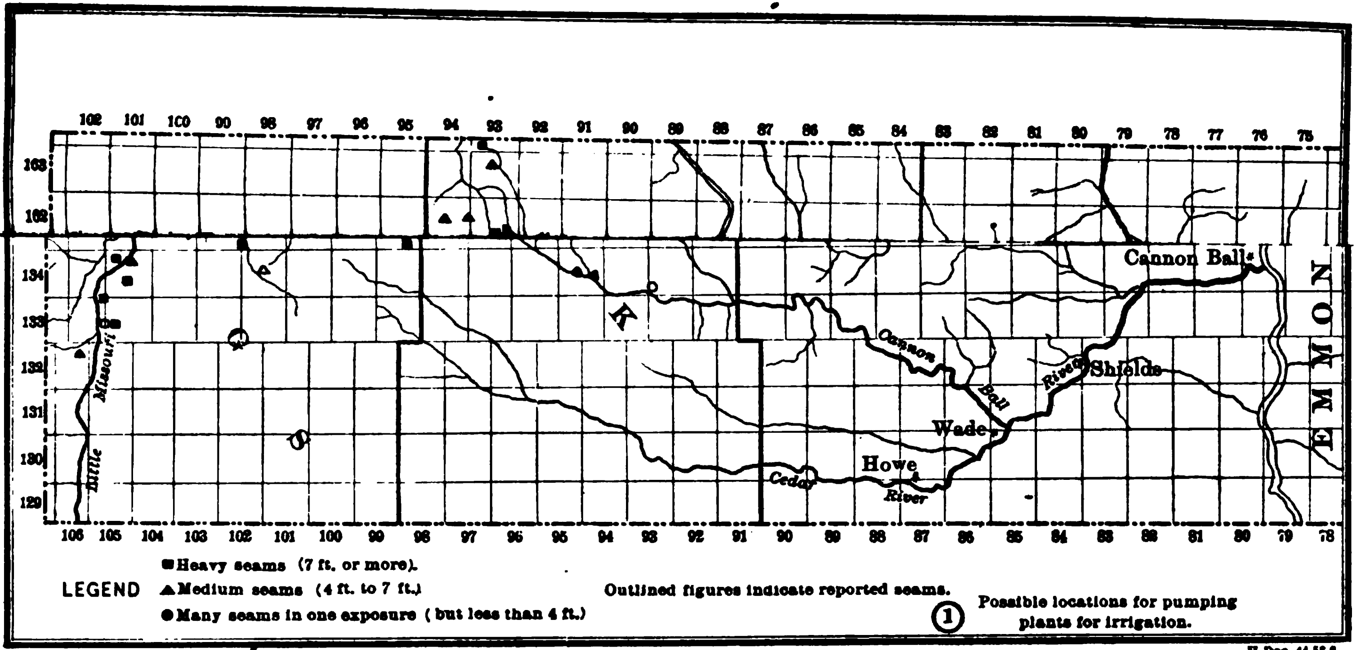
*Manual of Irrigation Engineering, pages 40, 41 and 322.

†Second Biennial Report, North Dakota Geological Survey, 1901-3.

Diameter of Discharge Opening.	Capacity in Gallons per Minute.	Horse Power Delivered to Shaft Necessary to Give Economical Discharge at Elevations Named.				Efficiency of Pump—Percentage.	Amount of Lignite in Tons Required to Furnish Power to Operate the Pump Twenty-four Hours Elevating the Economical Discharge.				Price of Pump.	
		20 ft	40 ft	60 ft	80 ft		20 ft	40 ft	60 ft	80 ft		
6	1,050	11.8	23.6	35.4	47.2	45	1.2	2.4	3.6	4.8	$120	$280
8	2,000	22	44	66	88	46	2.2	4.4	6.6	8.8	190	390
10	3,000	32	84	96	128	47	3.2	6.4	9.6	12.8	240	570
15	7,000	70	140	210	280	51	7	14	21	28	400	840
18	10,000	100	200	300	400	52	10	20	30	40		900
20	12,000	120	240	360	480	53	12	24	36	48		
24	15,000	130	260	390	520	58	13	26	39	52	1,700 Volute	
36	32,000	260	520	780	1,040	62	26	52	78	104		



L. L. POATES, ENGR., N.Y.

H. Doc. 44 58 2

Outcrops of lignite examined during the summers of 1902-3. The position of the old valley, referred to in the text, and the larger flats, are indicated (the last by numbers).

RIVER FLATS AND LIGNITE ALONG THE MISSOURI

Geological work undertaken during the summer of 1902 along the Missouri river had made evident the existance of large quantities of lignite at a number of points on this stream, and of extensive flats of moderate elevation.

To determine the abundance of lignite, the amount of land included in the flats and the size of the more extensive tracts, in the summer of 1903 a party of three followed the river from the Montana line to the mouth of the Cannon Ball river. The more extensive flats studied at this time are described separately on the following pages. Smaller flats of from 100 to 500 acres were of too frequent occurence to permit of detailed examination. The larger maps of the Missouri River Commission were found most helpful, and should be secured by any one who proposes to locate one of the smaller flats on the Missouri for the purpose of irrigation and farming.

The Yellowstone Flat in North Dakota.—On entering North Dakota, the course of the Yellowstone is toward the northwest, then north,. and just before uniting with the Missouri flows for nearly two miles somewhat south of west, its total course in the state amounting to about fifteen miles. For this distance it keeps close to the bluffs at the right bank of the valley, leaving broad benches unbroken by meanders on the left. Above the flood plain, which is covered with a dense growth of willows, is a wooded bench from ten to fifteen feet above high water, where large cottonwoods flourish. Its extent may equal 4,000 or 5,000 acres. Ten feet above this, and twenty feet above the river at high water is the edge of a beautiful and extensive grassed terrace which rises gradually for two miles to the foot of the bluffs, and below the contour line that might be drawn eighty feet above the river will include about 15,000 acres. It is not cut up by ravines or gullies, and a trench can be carried along the eighty foot contour with but few flumes, and water can be conveyed to almost any point on the flat if it has this initial head. The soil is a good loam and the upper terrace is already well grassed, though at present it yields hay regularly only where naturally irrigated by water that comes down in Four and Eight mile creeks and other coulees and spreads out over its surface. Much of the woodland lies high enough above the river to be free from ordinary river floods and is inundated only at rare intervals and then on account of the gorging of the ice. In all, at least 15,000 acres on the left bank of the Yellowstone in North Dakota may be regarded as fit for irrigation, if water from the river can be raised eighty feet.

The area in North Dakota is but part of flats that extend into Montana as far as Terry. The fall of the Yellowstone is but 2.7 feet per mile and a slope of a foot per mile would probably be needed in a lateral ditch. A very long lateral will be necessary to take the water from the Yellowstone and cover the flats, if gravity is relied on alone.

Heavy deposits of lignite occur near Sidney, Mont., fifteen miles west of the North Dakota line, and on the Yellowstone river. On the creeks which empty into the Yellowstone from the south, notably Charbaneau creek, heavy beds of lignite are said to outcrop.

The Buford-Trenton Flat.—Extending along the north side of the Missouri, from the state line to the eastern edge of the old Fort Buford reservation, a distance of sixteen miles, is an extensive flat which needs only water to become highly productive. At Trenton station, in the middle of this tract, the river swings in abruptly till it is close to the bluff and the flat is narrow here for half a mile. Enough remains, however, so that if water were available and it seemed desirable the level bench both east and west of Trenton could be irrigated from a single central station.

The flat includes some 12,000 acres, divided between an upper, grassed terrace and a lower, wooded bench, the former exceeding the latter by about two to one. The wooded bench is from twenty to twenty-five feet above ordinary high water and is said to have been flooded but twice in twenty-eight years, the last time in the spring of 1891. In places it is being cleared and cultivated. Although sandy in places, for the most part it has a good soil. The second, or grassed terrace, rises gradually from the edge of the wooded terrace, where it is about thirty feet above high water, to the bluffs at whose base it is eighty feet above the river. It has a strong gumbo soil and grows blue-joint, or wheat grass, with cactus and sage when unirrigated, while with irrigation it is abundantly productive both in grass and grain.

The vegetation on this flat when not irrigated is shown in plate 2, while plate 3 shows an adjacent tract that has been irrigated by flooding for two years. The cactus and sage brush

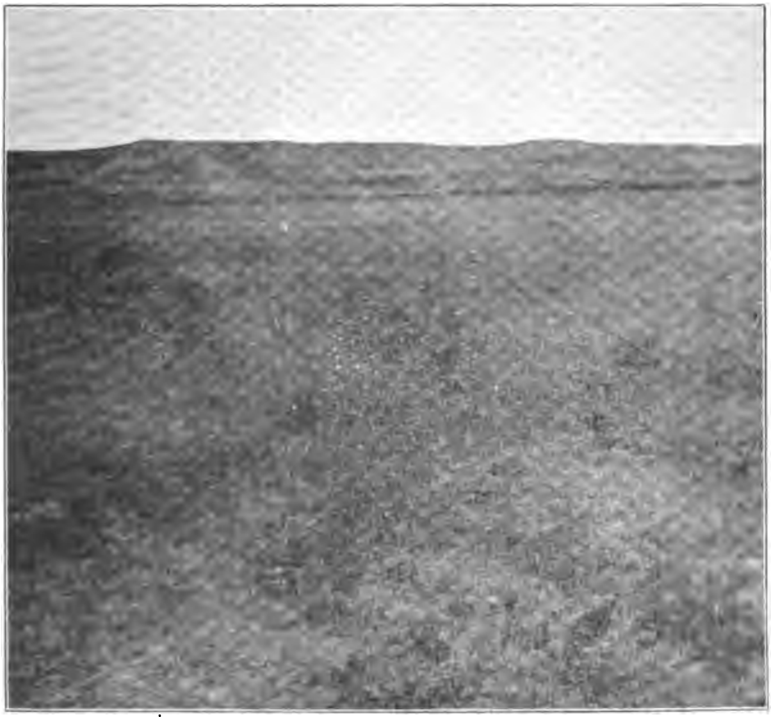


Fig. 1. Flat at Trenton, not irrigated

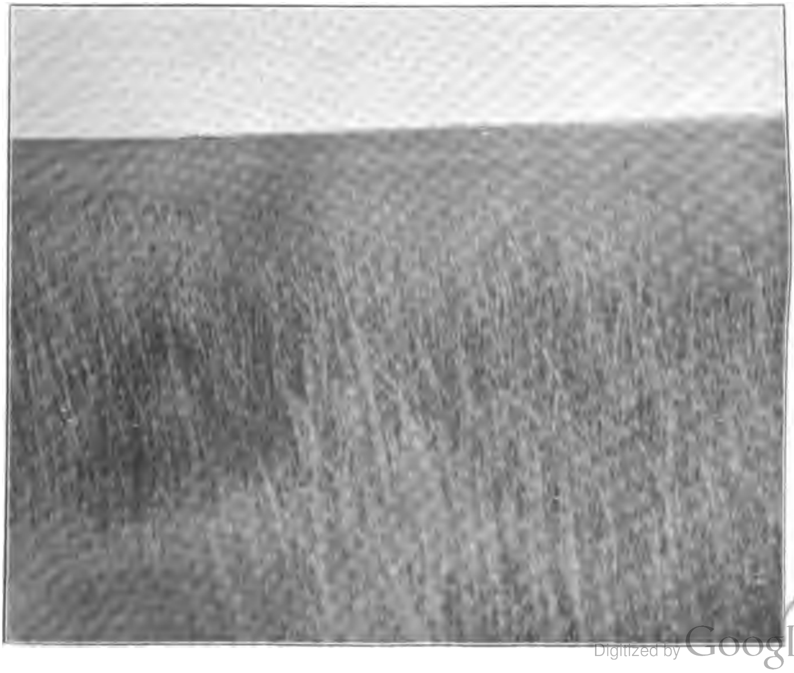


Fig. 2. The same flat under irrigation

have given place wholly to the blue grass, which grows luxuriously, yielding two and a half tons of excellent hay to the acre. The Great Northern railway crosses it, running at the foot of the bluffs, and produce raised on it will find easy access to market.

The efforts now being made by Mr. Edwin Jack and others, to irrigate parts of this area are described on another page. It will be possible to irrigate a portion of it, as they are doing, by building reservoirs and diversion dams in the draws that cut the bluffs behind the flat, but for a large portion of it the economy of this method may fairly be doubted. For the area as a whole it will be advisable to consider the possibility of raising water from the Missouri river.

Coal near the Buford-Trenton Flat.—Only limited quantities of lignite are known in the bluffs just back of this tract, though large beds may sometime be discovered. Two miles from Buford, in Township 153, Range 103, Section 31, a four-foot bed of good lignite is mined to a limited extent by stripping. About seventy-five tons were taken out in the winter of 1902.

On Eight Mile creek, above Ed Jack's ranch, a three and one-half-foot seam furnishes some lignite, while fuel from Buford is in part brought from the Yellowstone, from the seams in Glass Bluffs across the river and four miles to the southeast, the hauling being done in the winter when the river is frozen. At Glass Bluffs lignite outcrops in a number of seams, as is shown by the following section:

	FEET
Glacial drift	25
Gravel	4
Clay, seams of various colors	140
Lignite, poor	.5
Clay	4
Lignite	3
Clay	7
Lignite	3.5
Clay, yellow	35
Lignite, just below high water (reported by E. E. Jones of Buford)	4.1

When visited the lignite forming the lowest member of the section was not visible.

If a pumping station were established at Trenton, where the river cuts back nearly to the bluffs and divides the tract in question nearly in two, it might be practical to ship coal from the mines already opened in the vicinity of Williston, a distance of only twenty-five miles. In this case good lignite f. o. b. cars at Trenton will cost $2.50, a price quoted this fall by responsible persons.

The lift at this point, to cover the entire tract of 12,000 acres, will be about seventy feet, though a large part of it could be watered with a lift considerably less.

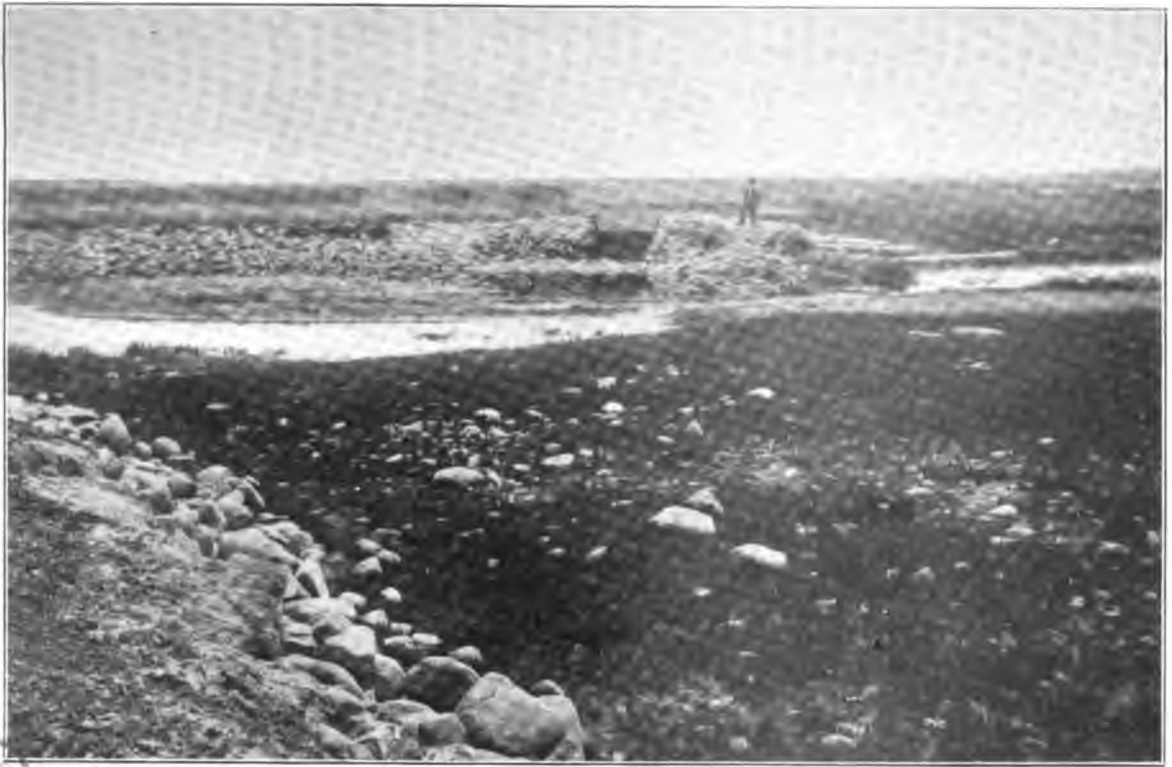
The Little Muddy and Missouri River Flats at Williston.—The Little Muddy is the main tributary of the Missouri from the east and north in North Dakota. Its drainage area includes nearly one-half of Williams county, or 700 square miles. In addition to a water supply from direct rainfall it is fed by a number of perennial springs. On June 27, 1903, it had a flow of eighteen second feet, and this amount of water was said to be normal for that season of the year.

Its valley is broad and in the main fertile. The bottom lands often are a mile wide, while a strip half a mile wide that is fit for irrigation may be counted on for twenty miles or more from its mouth. There may be 10,000 acres along the stream that could be irrigated, if it can be shown that water can be found for so large an area.

Along its tributaries there is much land not included in the above estimate, portions of which are already irrigated, mainly by diversion dams for spring flooding.

To be taken with the Little Muddy river flats, are three or four thousand acres on the Missouri at Williston, between this town and the mouth of the Muddy. It is probable that the amount of water that the Muddy annually contributes to the Missouri is more than adequate to water the 15,000 acres that lie near it, but it has not been demonstrated that a large reservoir can be located on the stream economically. Its valley for fifteen miles is broad and offers no point where a short wall can retain any considerable amount of water. If a dam were erected above this point the water from some of the principal tributaries, which empty below, would be lost. The Fred Rounsaville dam, which was intended for a diversion dam rather than for a reservoir, has been described on another page.

There is an abundance of lignite on the Big Muddy and its tributaries, and along the Missouri below Williston. Banks that are opened up for local use about Williston and on the creeks to the north are as follows:



The Rounsaville dam on the Little Muddy above Williston

The Mackersie bank on Sand creek, in Township 154, Range 101, Section 6.

The Holland bank, close to the Muddy river and six miles north of Williston, where a heavy bed of lignite is exposed.

The Lovejoy mine on Stony creek, where considerable beds outcrop close to the Great Northern railroad.

The mine of the Pioneer Coal Company is more extensively developed than any of these and lignite is shipped from it in considerable quantities. It is located directly on the railroad, which here follows the valley of Stony creek, in Township 155, Range 100, Section 26. The bed mined is six feet thick.

The Miller mine on Cedar coulee, a tributary of the Missouri, is located four miles east of Williston. A twelve-foot bed here outcrops and will furnish a large amount of excellent coal.

A number of lignite outcrops four and six feet thick occur along Cow creek, a tributary of the Big Muddy, and are mined to some extent for local use.

The old Dahl mine, three miles southeast of Williston, was located on a four-foot outcrop in the Missouri river bluffs, on the left bank of the river.

A mile farther down the river on the right bank, in a single vertical section, eight lignite beds outcrop, the thickest being four feet.

On account of the location of the flats about Williston, their nearness to the railroad and to the town, and because most of the settlers in the Big Muddy valley are desirous of leasing water from some responsible party, a careful study of the valley is recommended.

The Nesson-Hofflund Flats.—The postoffices of Nesson and Hofflund are situated on the Missouri river, about thirty miles east of Williston and fourteen miles south of the Great Northern railroad, the nearest station being the town of Ray. Hofflund is six miles east of Nesson.

In this vicinity the Missouri receives a number of tributaries. South Tobacco Garden and Clark creeks unite with it from the south, and North Tobacco Garden, Beaver and White Earth creeks from the north.

Two extensive flats or terraces are developed here, one from twenty to forty feet above high water, extending from Nesson to Hofflund, some six miles along the river, and the other from eighty to 100 feet high and located back of Nesson. The upper terrace includes 7,500 acres, held by more than thirty homesteaders and settlers. The lower flat includes about 6,000 acres. The soil of the upper bench is sandy loam with clay subsoil, excepting a narrow strip along the lower edge which is gravelly. The lower bench has from one to four feet of fertile, sandy loam on its surface and sand for a subsoil. A portion of the lower flat is wooded, but for the most part at this point the woodland is confined to the flood plain, which is not here considered as part of the lower terrace. A portion of the lower terrace is suffering considerably from the inroads of the river, but the loss due to this cause is not serious enough to interfere with any scheme for the development of the flat as a whole. The slope of the surface of both terraces is favorable for irrigation.

For many reasons the region invites study with reference to the possibility of irrigating it in an extensive manner. The area, especially when both terraces are considered, is considerable, the soil inviting and the distance from a railroad shipping point only fourteen miles. Heavy seams of lignite of good quality outcrop in the immediate vicinity, and a pumping station that would furnish water for the lower flat may, it is thought, be placed close to one of these outcrops and the hauling of fuel be greatly reduced or wholly obviated. On account of the lift it will hardly be practical to irrigate the upper flat with water elevated from the river, and North Tobacco Garden, Nelson and Beaver creeks may be considered as possible sources of supply.

North Tobacco Garden creek, which unites with the Missouri at Nesson postoffice, has a drainage area of twenty square miles and is fed by strong springs. Cusack springs, at the source of its west fork, in Township 154, Range 98, Section 12, are perennial and flow three second feet even in midsummer. Deer coulee heads at a spring about as strong and unites with North Tobacco Garden creek a few miles above Nesson. During the summer the creek suffers some loss of volume because of the porous nature of the stream bed at some points. On July 4, 1903, it had a flow of five second feet at its mouth, an amount somewhat less than that of its spring sources.

At least two suitable reservoir sites seem to exist on North Tobacco Garden creek, one occurring a mile back of the upper Nesson flat, where the creek emerges from the bluffs. Another site, with apparently a larger capacity, occurs five miles further up the creek. The ability of the creek to furnish water enough

The Rounsaville ditch on the Little Muddy above Williston. The width of the valley is here shown

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to fill extensive reservoirs, however, has not been demonstrated. Nelson creek, which drains forty square miles, could also be used, as it is now in a measure, in irrigating the upper flat. It is spring fed, though the springs are weak and most of its available water is due to the melting of snow in the spring. On another page the tracts at present irrigated in this vicinity were noted.

Beaver creek drains 120 square miles in southeastern Williams county. On reaching the Missouri river flats it turns to the east and its bed gradually becomes ill defined, until at last it spreads its water over the nearly level surface. Six miles above its mouth, on July 8th, its flow was eighteen second feet, which was considerably more than its flow nearer the mouth. In the spring of an ordinary year its discharge is considerable. Its descent is rapid and it seems possible to utilize its waters, if they can be properly stored, to irrigate at least a part of the upper terrace.

The water from these three creeks would seem sufficient to irrigate the 7,500 acres on the upper flat, which on account of the elevation of from eighty to 100 feet, can hardly profit by any scheme to utilize the water of the Missouri river.

On these creeks boulders are fairly abundant. Aside from these and beds of soft sandstone no other stone occurs in the vicinity that could be used in reservoir construction.

For the lower flat, which includes 7,000 acres, pumping from the Missouri may be practical, for fuel is abundant, as shown by the following list of lignite outcrops that occur in this region.

At Spanish Point, on the opposite side of the river and four miles farther up, four heavy beds outcrop in the bluffs. The aneroid gave the following elevations for the beds:

Aneroid reading at top of bluff	2,850 feet
Lignite, three feet, at	2,730 feet
Lignite, six feet, good, at	2,690 feet
Lignite, fifteen feet, good, at	2,500 feet
Lignite, eight feet, good, at	2,450 feet
High water of river, about	2,400 feet

The elevations show merely the relative positions of the beds, and may vary considerably from the absolute elevations. The bluff is one of the highest in the state.

On Deer coulee, a tributary of Beaver creek, at the Marmon ranch, four miles from Nesson postoffice, a ten-foot seam of good lignite outcrops and a strong spring issues from it. A seam of this thickness is reported at a number of points at about the same elevation as this outcrop and the bed may be regarded as rather extensive.

Along North Tobacco Garden creek two seams, six and eight feet thick, outcrop at a number of points, both seams often being exposed in the same vertical section. They can furnish great quantities of good lignite.

On Beaver creek a four-foot bed outcrops frequently and is used locally. Three miles above Hofflund a ten-foot bed is mined somewhat more extensively. An entry has been carried in thirty feet. It lies so low that in high water it is partially filled from the creek.

In the bluffs across the Missouri Mr. H. A. Carey takes coal from a six-foot seam.

Lauchland's bank, located close to the west end of the lower flat, is said to show a good bed of lignite about eight feet thick.

At Stony point, on the right bank of the river, between Nesson and Hofflund, two beds of good lignite, each three feet thick were seen, and a heavier bed is said to outcrop at this point.

The Fort Berthold Agency Flats.—The flats about the present agency on the Fort Berthold reservation, which are low enough to justify study with reference to irrigation by pumping from the Missouri, include 5,000 acres. Of this, perhaps 1,200 acres were formerly woodland which was recently burned over, leaving them practically clear while 800 acres are still covered with large trees. This woodland area is but twenty feet above high water, has a sandy loam soil and is very rarely covered by water during ice gorges. Twenty feet above this lies a well grassed flat of 1,200 acres, and still higher, perhaps eighty feet above the river, is a terrace containing some 2,000 acres.

Lignite outcrops frequently in the vicinity. Directly across the river, at high water level, three and a half feet of lignite were exposed on July 8, 1903, and the bed was reported by the superintendent of the agency to be ten feet thick. It has supplied coal for the agency during the winter, when the river is low and crossing on the ice is possible.

In the bluffs, three and one-half miles below the agency and on the same side of the river, a nine-foot bed, with a foot of clay in the middle, outcrops fifty feet above the low river flat. A half mile further south the following section is exposed:

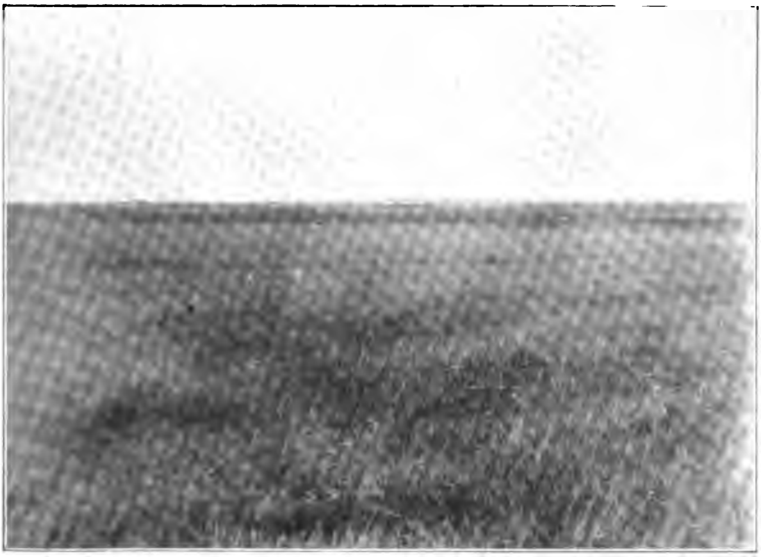


Fig. 1. Part of the upper terrace at Nesson

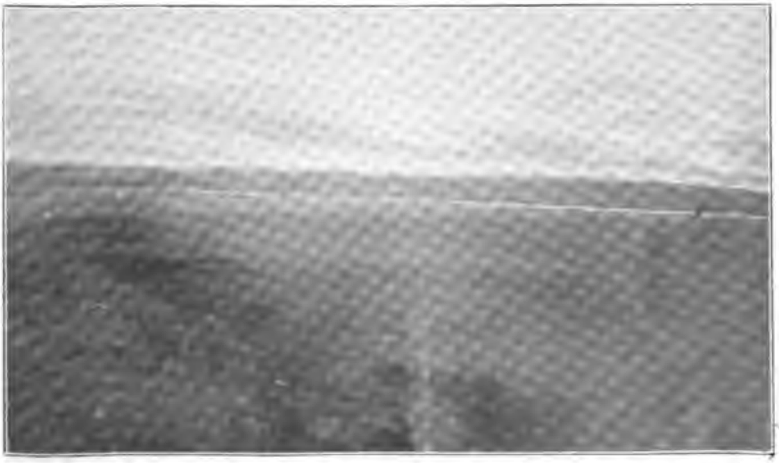


Fig. 2. One of the larger flats on the Missouri river, forty feet above water level

	FEET
Lignite, six inches of clay in the middle	6
Clay	20
Lignite	2
Clay	5
Lignite	3
Clay	50
Slope to lower river flat	20

All of the lignite in this section seems to be good.

Seven miles below the Berthold agency, Mr. W. C. Dean reports a twelve-foot bed of lignite, from which he hauls coal to the agency.

Lignite in beds of workable thickness outcrops in the bluffs back of Elbowoods at a number of points.

The Old Fort Berthold Agency Flats.—About twelve miles below the present agency is the group of buildings that it formerly occupied. They stand at the upper end of a beautiful river flat, which contains some 4,000 acres. Its elevation is from twenty to eighty feet above the Missouri, which bounds it on the south. It is well grassed.

In the bluffs just east of the flat, a five-foot bed of good lignite is exposed about fifty feet above the river. On the opposite side of the river, in the broken ground back of Dancing Bear valley, a five-foot bed is mined by stripping. A four-foot and a three-foot seam outcrop in the bluffs a mile south of this mine.

The Fort Stevenson Flats.—These beautiful flats include about 7,000 acres, and lie on the north side of the river, a few miles northeast of Coal Harbor. Their elevation is from thirty to seventy feet above the Missouri, and its slope is gradual and uniform from the bluffs to the river.

Coal occurs abundantly in the bluffs just back of the flats. For many years lignite was mined here for use at the fort and Indian school formerly located here. The exact location of the mine was Township 148, Range 85, Section 35, southwest one-half. A seam said to be fourteen feet thick was mined by stripping. When seen the lower part of the excavation had filled in and only the upper two feet of lignite were visible. This mine is about thirty feet above the river flat. Higher up in the bluffs other lignite seams occasionally outcrop, the best exposures seen occurring half a mile east of the Fort Stevenson mine. Here three seams were noted, the thickest being six feet. Lignite outcrops also along two creeks in this locality. In Township

147, Range 84, Section 24, a lignite seam was visited, said to be eleven feet thick, though but seven feet could be seen at the time, the lower portion being covered with recent wash.

On the opposite side of the river seams three and four feet thick are nearly continuous in outcrop for ten miles.

The Apple River Flats.—Just south of Bismarck are extensive flats, which lie in the form of a triangle, the Missouri river lying on the west, while Apple river and the bluffs back of Bismarck form the sides on the east and north. They include some 5,000 acres, 2,000 acres being only from twenty to thirty feet above the river and partly wooded, while the remainder is from eighty to a hundred feet above river level. No coal outcrops in the immediate vicinity, but the expense involved in bringing lignite from the thick beds outcropping directly on the river sixty miles above, at Mannhaven and Coal Harbor, should not be great. It may be more practical to control the water of Apple river and use it for irrigation purposes, for the stream drains a considerable area and could doubtless furnish all the water needed if it could be properly stored.

On account of their situation on the outskirts of a city of considerable size, and on the Northern Pacific railroad, gardening should prove remunerative, and a rather high cost per acre to secure irrigation may be justified.

The Big Bend and Shell Creek Tract.—The Missouri river just before entering the Fort Berthold reservation receives the waters of the Little Knife. Then instead of pursuing its normal course it makes a notable bend like a great letter U. This portion of the river is known as the "Big Bend." Throughout this portion of its course and in the valley of Shell creek, which meets it at the lower end of the U, topographic conditions and the heavy beds of lignite present invite a careful study with reference to irrigation possibilities, though the conclusions that may be reached are probably more uncertain than in the flats already described. The area, however, is large, and the land lies wholly within the reservation and is still completely under government control.

The river at the "Big Bend" seems to have been diverted from its course at some time in the past, perhaps by the Wisconsin ice sheet, and compelled to cut a new channel to the west. Its former channel appears to connect the two arms of the U and form a valley two miles across, with its center, a third of a mile across, sloping very gently and unbroken by gullies. Its position is shown on map I. At the upper end of the U this old valley is 140 feet above the river. Its slope is toward the south and the upper half drains into a large slough in its center, while the lower portion contributes its water to Shell creek. The area that could be irrigated advantageously, if water could be found, is two-thirds of a mile wide and fifteen miles long, including some 7,000 acres of good soil. In addition to this, on the Missouri, at either end of this old valley, are flats which contain 3,000 acres.

Six and a half feet of good lignite outcrop in the bottom of a draw about eighty feet above the river, and the bottom of the seam was not found. One-half mile down the river, in the bluffs at the point marked B, the following section is given:

	FEET
Lignite	5.5
Clay	5
Lignite	7
Clay	50
Water level.	

One hundred yards farther down a section partly covered by talus gave:

	FEET
Lignite	4.5
Clay	5
Lignite	3
Clay	50
Water level.	

The quality of the lignite in all of these beds was good.

Three and a half feet of good lignite outcrops in a cut bank known as "the slide." This same seam probably gives rise to the spring in the bluffs two miles to the north, where the Indians have dug through two feet of lignite to give freer vent to the water. It is persistent in outcrop for three miles to the south, though showing but few good natural exposures.

Although the exposures noted indicate a great abundance of lignite in seams from four to seven or more feet thick, the amount of the lift may render pumping from the Missouri out of the question. Shell creek drains more than 125 square miles, and its water may be available, at least for portions of the area, and for areas of 600 to 1,000 acres that are found along the valley of this stream. The flow of water in Shell creek on July 17, 1903, was about six second feet.

THE SMALLER FLATS ON THE MISSOURI RIVER, AND THE LIGNITE IN THEIR VICINITY.

Some of the many flats on the Missouri, limited in extent, but not so high as to render pumping from the Missouri out of the question, should be noted in addition to the more extensive tracts already described. Much of the woodland on the upper edge of the flood plain can doubtless be cultivated after clearing. Its soil is generally fertile and its value as timber land small. These tracts are not included, however, in the flats mentioned below.

On the south side of the Missouri, at the edge of the old Fort Berthold reservation, 1,200 acres, forty feet above the river. No coal showing in the immediate vicinity.

On Little Muddy Cut Off some ten miles below Williston, on north side of the river, 700 acres, twenty to forty feet above the river. Lignite six feet thick in the bluffs a mile below.

At Barker's Bend, a good flat of 600 acres, with twelve feet of lignite in "sliding bluff" just below.

Opposite Nesson, flats containing 1,200 to 1,500 acres from twenty-five to fifty feet above the river, with the heavy beds of lignite in Spanish Point already described three miles away.

Opposite the mouth of White Earth creek, an area of 600 acres, with three lignite beds, the thickest four feet, in the bluffs just behind.

Opposite the mouth of the Little Knife, 2,000 acres in two terraces, one twenty the other forty to eighty feet above the river. One lignite bed four feet thick was found in the bluffs behind this flat.

At the Indian village of Independence, 1,000 acres, eighty feet above the river. Lignite outcrops in a four-foot bed just across the river.

Five miles below the mouth of the Little Missouri on the east side, an area of 500 acres in two terraces, with lignite outcropping in a four and a half foot bed just opposite.

Just below the Fort Berthold agency on the opposite side of the river, a long narrow flat containing 2,000 acres, fifteen to twenty-five feet above the river, extending to Little Beaver creek, where four feet of lignite outcrop in the river bluffs.

Just above the town of Mannhaven, 1,500 acres, forty to fifty feet above the river. Eight feet of good lignite outcrop on the river at Mannhaven, with thinner beds, as shown in the following section:

	FEET
Lignite, good	6
Clay	2
Lignite	1
Clay	1
Lignite, good	2
Clay	10
Lignite, good	8
Sand	12
Water level.	

This section may be seen for 2,000 feet along the river.

At Hancock, 1,500 acres in a series of terraces fifteen to twenty-five feet above the river. Four feet of coal outcrop in the bluffs behind, while across the river the heavy beds once developed and known as the "Plenty" mine outcrop. The beds there exposed show:

	FEET	INCHES
Lignite	3	
Clay		6
Lignite	3	
Clay	2	
Lignite	3	

Mr. F. G. Mattoon is putting in a pumping plant to irrigate portions of these flats.

Two miles above Stanton, on the opposite side of the river, 1,000 acres, fifteen to twenty-five feet above water level. A seven-foot lignite bed outcrops close to the water on the edge of this flat.

Opposite Washburn, 3,000 acres in three terraces, at least portions of which are subject to irrigation. Six lignite exposures showing from three to seven feet of coal occur in the bluffs and coulees behind the flats.

The flats at Painted Woods Lake, 3,000 acres, with four feet of lignite in a neighboring draw and a five-foot bed exposed on a creek on the opposite side of the river, near Sanger court house.

At the mouth of Square Butte creek, eight miles above Mandan. Two feet of lignite are reported two miles to the north.

Near Mandan and at a number of points farther down the river are extensive flats, but no heavy beds of lignite are known to occur near them.

RIVER FLATS AND LIGNITE ON THE HEART RIVER.

Attractive flats, each containing a few hundred acres, may be found all along the Heart river and its tributary, the Green river. Lignite outcrops along both streams are likewise frequent. Some of the largest mines in the state are located near them. The New Salem mines, but twelve miles north of the Heart river, during the year 1902-1903 had an output of 17,000 tons. Other mines producing extensively at Sims, are no farther from the river. Between New Salem and the river five-foot beds outcrop at a number of points and are mined on the strip-pit plan.

The mine of the Consolidated Coal company at Lehigh, three miles east of Dickinson, has developed a remarkably fine bed of lignite which varies in thickness from twelve to sixteen feet. It outcrops continuously along the river for three miles. Thirty feet above this thick bed, a three-foot seam is frequently exposed and above this another and more variable bed.

Lignite at Dickinson.—At two points on the outskirts of Dickinson lignite is mined in considerable quantities. At the plant of the Dickinson Pressed Brick and Fire Clay company, a five-foot bed is mined by stripping. The Lenneville mine, half a mile east of Dickinson shows a bed varying in thickness from four to eight feet. From this mine lignite ordinarily sells at the mine for $1.50.

Lignite on Green River North of Dickinson.—Throughout its course lignite abounds on Green river. Near its mouth at Gladstone beds of excellent quality, though not exceeding five feet in thickness, are found on the Rust and A. B. Powers' farms in Township 140, Range 95, Sections 26 and 27. The exposures are directly on the river and near water level. Two miles farther up the stream, in Township 140, Range 95, Section 22, west half, a three foot bed of good lignite is mined by the owner of the ranch on which it occurs. At the Kupper ranch, due north of Dickinson, a fifteen-foot bed of excellent lignite outcrops for a long distance on the edge of Green river. This bed is known to be very extensive.

Three and four miles west of Dickinson, on the Heart river, a four and a seven-foot bed outcrop frequently. The seam mined at the Bird-Stone mine, in Township 139, Range 98, Section 6, outcrops on the Heart river and may be seen from the cars of the Northern Pacific railroad. A sixteen-foot bed is mined, the upper part of the bed being inferior in quality at the outcrop. The lower eight feet is excellent. In Section 8 of the same township the bed outcrops again. On the south side of the

Little Heart, between South Heart station and Belfield, a six-foot bed of excellent coal occurs. It may be best seen in Township 139, Range 98, Section 16, a school section.

Coal North of Belfield.—Coal Mine creek, a tributary of the Heart river which unites with it a mile east of Belfield, shows great quantities of lignite along its course for at least five miles. Two good banks were examined, one in Township 140, Range 98, Section 28, six feet thick, and the other in Township 140, Range 98, Section 27, four feet thick.

A number of additional openings have been made along this creek from which lignite is taken. In Township 140, Range 99, Section 30, five feet of a bed said to be nine feet thick may be seen.

Lignite South of Belfield.—Three miles south of Belfield, on Norwegian creek, a tributary of the Little Heart which flows east and unites with the parent stream eight miles southeast of Belfield, a number of beds are exposed and slightly opened. They include:

	FEET
The Englehardson bank, Township 139, Range 99, Section 20	6
The Anderson bank, Township, 139, Range 99, Section 19	12

In the vicinity of all of these lignite outcrops there are flats of moderate elevation.

RIVER FLATS AND LIGNITE ALONG THE CANNON BALL AND CEDAR RIVERS.

Terraces of varying elevations and including considerable areas occur along the lower course of the Cannon Ball from its union with the Cedar and along both streams for sixty miles above their junction. On account of the meandering of the rivers and the rather limited width of the terraces, more than 600 acres are rarely found in a single tract. With the data now at hand it does not seem practical to irrigate areas larger than this by pumping from a single fixed station. It may be, however, that detailed study will show that two or more of these tracts may be connected by ditches and treated as one.

The elevation of the Cannon Ball flats varies from ten to eighty feet. The soil is generally fertile and many of the flats are well grassed. Some appear to be gumbo, while others are too sandy to be desirable for agriculture. Taken together they present a considerable area, perhaps 30,000 or more acres with soil and topography favorable for irrigation.

As on the Missouri, there are opportunities for building reservoirs on the tributary streams and diverting the water so controlled to the flats of the larger stream. The difficulties here, as there, will be found in constructing at reasonable expense reservoirs sufficiently strong to withstand the strain put upon them by violent storms.

Lignite is not abundant on the Cannon Ball below Wade postoffice, where the Cedar unites with it. The following outcrops only were noted:

Three feet of coal reported in Castle or Palace Butte about six miles north of Cannon Ball postoffice, at the mouth of the river. Samples examined were of fair quality.

About eighteen miles from the mouth of the Cannon Ball, in Township 134, Range 81, Section 21, a fourteen-inch bed is mined by stripping. The outcrop occurs close to the river.

A bed two and a half feet thick is reported in a bank four miles northwest of Shields postoffice, and an equal distance from the river.

Three miles north of Howe postoffice a bed eighteen inches is reported.

A careful search made along the bluffs where good exposures occur brought to light only beds a few inches thick, till the upper Cannon Ball was reached.

Forty miles east of New England postoffice heavy lignite beds outcrop, and appear continually from this point for fifty miles up the stream.

The following beds may be briefly tabulated:

	FEET	
Township 134, Range 92, Section 31, O. S. Chase bank	2-3,	good
Township 133, Range 92, Section 4, E. C. Barry bank	3,	good
Township 134, Range 94, Section 21	3,	good
Township 134, Range 94, Section 22, NW¼	3,	good
Township 135, Range 96, Sections 21 and 22	4,	good

Near New England postoffice:

Township 136, Range 97, Section 22, Jacob Riess bank	7,	good
John Ermintrout bank, 6 miles N.E. of New England	3	
Five miles west of New England, directly on Cannon Ball river, in two beds, good	9	

On Coal Bank creek, a tributary of the Cannon Ball, which unites with it near New England, shows good lignite beds frequently. One four-foot bed may be found four miles from the mouth of the creek.

On the upper Cedar river lignite is said to be abundant, and from observations on the adjacent tributaries of the Cannon Ball the reports are probably correct. The same statement can be made for the upper Grand river in South Dakota.

RIVER FLATS AND LIGNITE ALONG THE LITTLE MISSOURI, ABOVE MEDORA.

Terraces are well developed along the Little Missouri at nearly every point in its course. In a given locality their number may be five or six, while few localities have less than three. Their elevation varies from twenty to 200 feet above the river. No single tract is large on account of the meandering of the river, but the total area at an elevation moderate enough to make pumping from the river practical is considerable. A rather careful estimate of the area not more than thirty feet above the river places it at more than 30,000 acres, cut up into tracts ranging in size from fifty to 1,000 acres.

During the summer of 1902 nine townships on the upper course of the Little Missouri, with Yule postoffice as a center, were studied. The topography of the country is diversified, including the Little Missouri valley and its terraces, the "breaks in the vicinity of the river and the rolling country back from the river which furnishes an unequaled summer range for cattle. Lignite outcrops even in the shallowest of coulees. Ranchmen seldom find it necessary to go far for fuel. Many of them consider it easier, however, to go to the river in winter and break up the great blocks of coal that the stream has washed out. More than half of the area had not been surveyed in September, 1902, and in many cases it is impossible to cite locations definitely.

In Range 105, Townships 133 and 138, which includes an area from twenty to forty miles south of the Northern Pacific railroad, a number of coulees head, which flow eastward into the Little Missouri river. In going from north to south, Williams, Garner, Bullion, Horse, Coal Canyon, Cannon Ball, Boise and Bacon creeks are crossed in about the order named. All of these creeks show lignite more or less continuously from the time that they cut through the sod until they empty into the Little Missouri, their courses varying in length from ten to twenty miles. None of these creeks, except Cannon Ball, are shown on an ordinary map.

Lignite on Williams Creek.—Six miles from its mouth the following section is given:

	FEET
Lignite, good	2
Clay	20
Lignite, good	4
Clay	4
Lignite, one foot exposed and bottom of bed not found.	

These beds were traced for a mile along the creek. Along the lower course of the stream lignite is said to be abundant.

Lignite on Garner Creek.—Exposures not abundant, though springs that probably come from the lignite are common, the lignite being concealed by the grassed slopes. A tributary which unites with the creek eight miles above the Little Missouri is said to show a four-foot bed.

Lignite on Horse Creek.—For more than six miles along this creek lignite beds varying in thickness from three to six feet are exposed at various elevations.

Lignite on Coal Canyon.—An abundance of lignite is exposed along the deep ravine through which this stream flows. A typical section is as follows:

	FEET
Lignite, fair	5
Clay	1
Lignite, good	7
Clay	1
Lignite, good to creek bottom	1

This exposure occurs two miles west of the Little Missouri.

Lignite on Cannon Ball Creek.—This creek empties into the Little Missouri about twenty-five miles south of Medora and is a stream of some importance, its valley being nearly a mile wide one mile from its mouth, where six feet of good lignite outcrop in a single bed. Along the Little Missouri and its tributary ravines in this vicinity four and five beds of lignite may be seen, ranging up to four feet in thickness.

Lignite on Boise Creek.—Some miles above its mouth two and three beds were seen ranging from two to four feet in thickness.

Lignite on Bacon Creek.—At the J. C. Gamel ranch in Township 133, Range 104, Section 20, a bed twenty-four feet thick outcrops. Its quality is good.

Lignite on Sand Creek.—A lignite bed *forty* feet thick outcrops near the A. E. Russel ranch, in Township 135, Range 101, Section 31. The exposure is continuous along the creek for a quarter of a mile, and much of the coal can be won by stripping less than ten feet of earth from the surface. At the north end of the exposure the section given was:

	FEET
Sandstone	2
Clay	10
Lignite	2
Clay	2
Lignite	15
Clay to water level	3

At the south end of the exposure the lignite reached the remarkable thickness shown below:

	FEET
Clay	5
Lignite	3
Clay	2
Lignite	40

The lignite throughout the bed appeared to be of good quality, except the upper two feet, which are soft. The analyses of this lignite indicate that the quality is good.

Lignite on the Little Missouri Near the 777 Ranch.—Some fine beds outcrop in this vicinity, which is some miles south of Yule. Rising directly from the water's edge at one point, the beds of clay and lignite reach a height of 110 feet. The heaviest lignite bed in the section is the lowest, which is more than twelve feet thick.

Lignite at Yule.—Two and three beds of fair thickness and quality occur near the postoffice of this name and at points between it and Medora.

Well developed river flats occur along the Little Missouri in this vicinity and at times exceed 500 acres in extent.

Both north and south of Medora for a number of miles lignite is as abundant as at the points cited. At some points, as near the Eaton ranch, it is mined for local use.

PRESENT STATUS OF IRRIGATION IN NORTH DAKOTA.

A great part of the irrigation in North Dakota is due to the stimulus given by the Desert Land Law. The application of this law in the state seems to have been free from abuse, and a further application of it has been prevented by the fact that extensive areas in the semiarid portion of the state are not recognized as desert land by the land office. The only portion of the state where desert land claims may be filed is the northwestern, and here there is always some uncertainty as to what the ruling of the land office will be till each claim is finally inspected.

On the Yellowstone flat in North Dakota and just over the line in Montana the following claims have been filed:

Andrew F. Nohle has a reservoir on Four Mile creek, a tributary of the Yellowstone in Montana, close to the boundary line. Four Mile creek is said to have a drainage area of twenty-four square miles, and the Nohle dam when completed will be twenty feet high in the center and the reservoir when filled will have a surface area of 388 acres.

A. W. Mann has a claim in Township 152, Range 104, Section 31, S. E. ¼, and proposes to obtain water from draws in the bluffs behind.

Sarah and Kate Mercer have desert claims on Township 152, Range 104, Section 32, N. W. ¼, and Section 31, N. E. ¼, and obtain water from draws. The main ditch to control these areas is already constructed.

On the Buford-Trenton flat, Mr. Edward Jack (postoffice Trenton) has been foremost in the effort to secure water for irrigation. Associated with him are Carl Wittmeier, Grant Conley and Charles Schumaker. A dam on Eight Mile creek which comes down from the north and spreads out over the Missouri bottom lands three miles west of Trenton, has been constructed across the creek bed, and the reservoir so formed has a surface area of 75.4 acres, and a capacity of 521.5 acre feet. The dam is of earth faced with stone, and has a suitable flume and waste gate. Its present capacity is regarded as sufficient, aided by the rainfall and inflow during the irrigating season, to care for 400 acres. The dam has washed out twice and has been rebuilt each time in a more substantial manner. Up to the present about $8,000 have been expended on reservoir and ditches. The results already obtained have satisfied the owners that the outlay is justified. The capacity of this reservoir could be increased considerably without great expense, and it is probable that water from Eight Mile creek would still fill it, if its capacity were not much above 1,000 acre feet.

Irrigation on Little Muddy Creek Near Williston.—The most notable attempt to irrigate in the vicinity of Williston was made

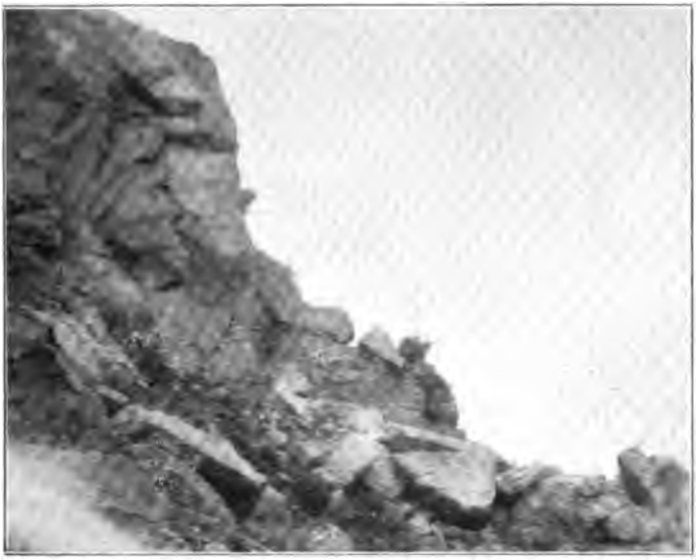


Fig. 1. Sandstone at the top of the Blue Buttes

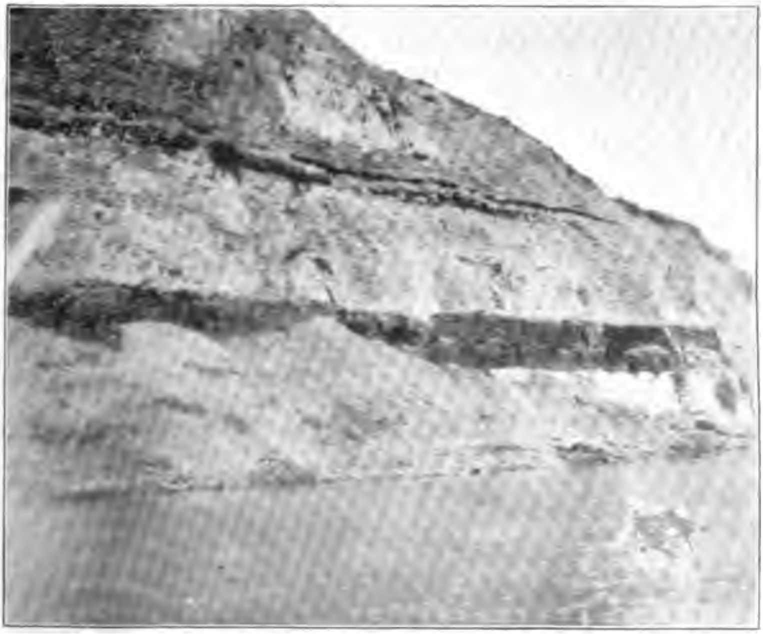


Fig. 2. Lignite at Mannhaven, exposed along the river

a few years ago by Mr. Fred Rounsaville of that place. On the Little Muddy, ten miles above Williston, in Township 153, Range 100, Section 5, he constructed a dam to divert the water from the stream and throw it into a lateral ditch which would irrigate the flats on the right bank of the Little Muddy and possibly a portion of the flats at its mouth, on the Missouri. No attempt to store the water was included in the plan. The dam was constructed and a portion of the ditch, when the work was stopped by the death of Mr. Rounsaville. The property is now offered for sale.

On the Little Muddy, above Williston, and its tributaries the following persons are irrigating to some extent, the operations for the most part being limited to spring flooding for grass.

George Marelius and Stephen A. Marmon have a reservoir in Township 159, Range 101, on Black Tail creek, a tributary of the Little Muddy from the west. They are said to be flooding 1,200 acres both for grass and grain.

The Freeman family are constructing a reservoir on the upper course of the Little Muddy, in township 158, Range 100, Sections 20, 23, 29 and 30 and are planning to irrigate 1,900 acres.

In Township 155, Range 98, Sections 28 and 29, Ellen Adams has a desert land claim which is now proved up. Water is taken from coulies that are dry in summer and the irrigation is for grass only.

Joseph Lansford has 320 acres which he irrigates in Township 157, Range 100, Sections 21 and 27, on the upper Muddy.

F. R. Zahl, in Township 159, Range 101, Sections 24 and 25 at the mouth of Scoria creek, a tributary of the Muddy, with his family, holds a section which he irrigates for grass.

On Cow creek, a tributary of the Muddy, L. L. and Howard Lampman irrigate two sections in Township 156, Range 102.

James Sherry, on Stump creek, a tributary of the Muddy from the west, in Township 156, Range 102, Section 2, irrigate a twenty-acre garden by pumping from a reservoir in the creek. During the year 1903 he pumped only four days, this with the rains being enough to mature a full crop of garden truck. An eight-horse power gasoline engine lifted 800 barrels an hour twenty feet. With gasoline at thirty cents a gallon the cost of operation per day of ten hours was $3. The owner estimates that, with the rain of an ordinary year to assist, his plant is capable of irrigating 160 acres. The soil is a sandy loam with clay subsoil. The cost of pump, pipes and engine delivered at

Williston was $811. Mr. Sherry has great faith in the profit to be derived from the enterprise and will extend the area that he irrigates next year.

Mr. E. A. Sharpe, on his farm two miles northeast of Williston, in Township 154, Range 100, Sections 17 and 20, is installing a ten-horse power gasoline engine and a centrifugal pump, which for his lift of ten feet has a claimed capacity of 735 gallons a minute. He intends to irrigate for grass and grain. Water will be taken from Stony creek and Little Muddy river. He estimates that he can irrigate 200 acres with his plant and that thirty days will be a maximum number for operation in an ordinary year.

At the mouth of Cow creek, on the Big Muddy flats, the Hedderick (formerly the Voss) ranch irrigates extensively for grass.

On Camp creek, in Township 155, Range 102, R. M. Calderwood, Grant Greenup, Francis Hendrickson and others have filed desert land claims and have made preparations to irrigate extensively.

At the mouth of the Little Knife Mr. Black has irrigated with profit for grass for a number of years.

Irrigation on Nelson Creek Near Nesson Postoffice.—The Nelson ranch, at the mouth of Nelson creek, on the upper terrace, is an illustration of the possibility of irrigating the upper terraces at that point at a moderate cost from the creeks coming from the upland. An earth dam at the mouth of Nelson creek diverts the water and by laterals it is spread over a considerable area, so that 600 acres or more are flooded in the spring. The ground is thoroughly soaked to a depth of two feet and is then allowed to stand a week before cultivation. On land so prepared oats often yield sixty bushels to the acre and wheat twenty-five, while the surrounding country, as favorably located except for the flooding, yields from nothing to ten bushels.

Irrigation on Beaver, and Its Tributary, Dry Fork, Creeks.—One of the earliest attempts at irrigation in North Dakota was made at the old Grinnell ranch at the mouth of Beaver creek, where by dams and ditches the water from the creek was spread over a number of hundred acres of the lower Hofflund flat. Part of the same area is irrigated in the same way by H. A. Carey. Carey's dam is twenty feet high and is not intended to store water in the creek bed back of it to any considerable extent, but to divert it to the laterals during the abundant water of the spring.

Ole Barsted has a dam and ditch on Dry Fork creek near its junction with the Beaver, and higher up on this creek are the dams of Wallender and Manly Anderson.

On Beaver creek above Carey's, water is diverted for irrigation by Nels J. Camp, Wm. Barsted and George Littlefield.

Mr. Ward is irrigating the east end of the lower flat at Hofflund, at the old Lampman ranch.

Mr. F. G. Matoon is putting in an extensive pumping plant to irrigate a portion of the fine flats on the Missouri at Hancock postoffice.

Irrigation as practiced at present on the Little Missouri and Knife rivers will be noted by Mr. Wood in his report.

RECOMMENDATIONS.

Opportunities to make application of the conditions of the Reclamation Act seem to exist in the larger flats on the Missouri river. A peculiar phase of the problem, however, is found in the fact that much of the land in these flats is already in private ownership. The flats which lie within the Fort Berthold reservation form the only exception to this statement.

In choosing among the Missouri river flats for one where the pumping plan may be tried under most favorable conditions, a number of factors must be kept in mind. Nearness to a railroad and a market are as essential as an abundance of cheap fuel and good land. An active interest on the part of the resident owners is necessary where the land is already in part or wholly private property.

With these conditions in mind, the flats at Buford and Trenton and the Nesson-Hofflund tract deserve first consideration. The former lies directly on the railroad. Lignite is not abundant here, however, and will cost about $2 a ton, whether mined in the vicinity or hauled from Williston. The Nesson-Hofflund flats are fourteen miles from the railroad; are wholly taken as private claims by parties eager to receive aid in irrigating; lignite is very abundant and should be laid down at the pumping plant for $1 a ton. It may be possible to locate the pumping plant within a few hundred yards of an extensive outcrop. From an engineering point of view, the Buford-Trenton tract seems somewhat simpler, though this must be left for the judgment of experts.

If a pumping plant is located at one of these points, it should prove whether the plan is practical for a hundred similar localities in the western part of the state.

The Big Muddy river above Williston deserves study. If a reservoir site can be found, the flats on this stream can be provided with water and an urgent need on the part of the settlers in the valley, who claim to be ready to pay a fair price for water, will be met.

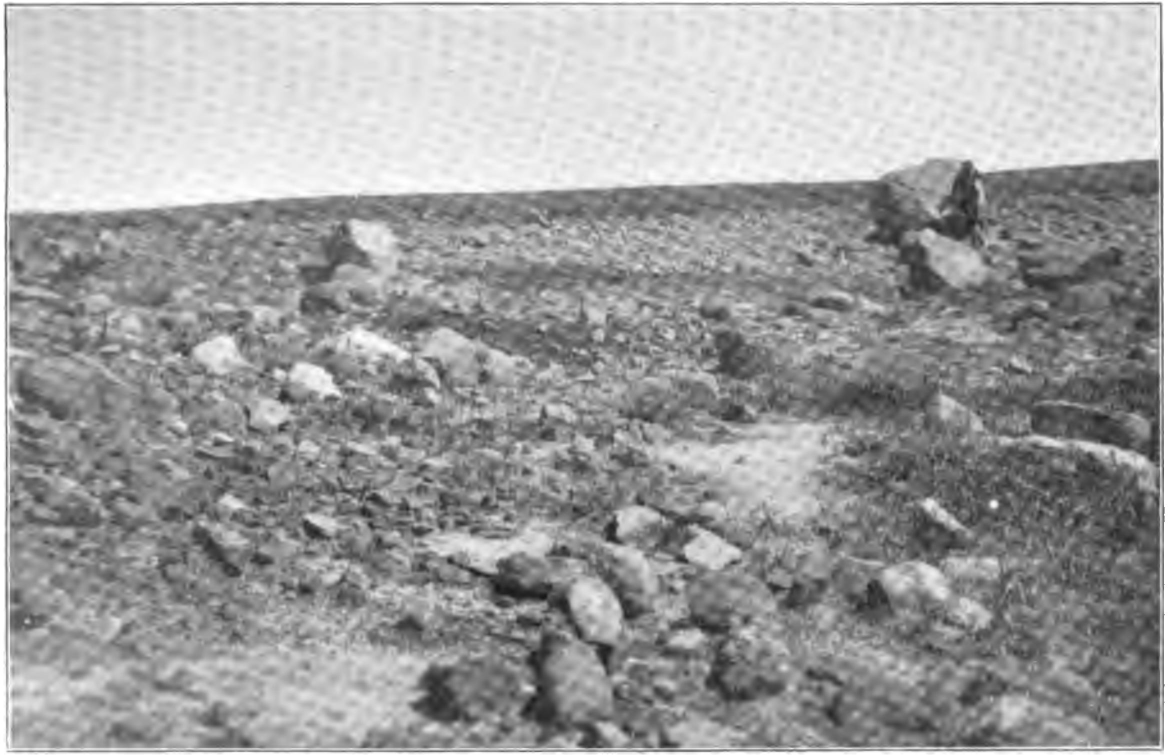
The Yellowstone flats in North Dakota form the most attractive single area for irrigation in the state. Since the gradient of the Yellowstone is somewhat higher than that of the Missouri, it may be practical to divert water from the river by starting well up in Montana. If this should prove too expensive, water may be moderately elevated by pumping at Sidney, Montana, where heavy beds of lignite are said to exist. From this point the water would be of constant service, both in Montana and North Dakota.

OBSERVATIONS ON THE GLACIAL DRIFT.

On the Cannon Ball river the extreme western limit of the glacial drift seems to be about ten miles west of the mouth of the Cedar river. For many miles east of this point the drift is represented only by boulders, which in places are quite abundant, as is shown in plate VII., which is made from a photograph taken on the Cannon Ball river, ten miles from the edge of the drift. The boulders here as everywhere near the edge of the drift lie directly on Laramie clays. Beyond the drift, in the southern part of the state, particularly in the Cannon Ball country, fragments of quartzite, which is regarded as residual, are very abundant, often literally paving the hill tops.

About Coal Harbor, which is eighty miles north of Bismarck, there are rather positive indications that an older Wisconsin drift occurs, which probably crosses the Missouri here and at points farther north. Unmodified and rather fresh drift is here found in the Missouri valley only a few feet above present high water. The topography of the upland at Coal Harbor is not more mature than that of the Iowan drift.

A more elaborate discussion of drift phenomena in the western part of the state is given in Mr. Wood's report.



Boulders on the Cannon Ball river, ten miles from the edge of the drift

REPORT ON THE REGION BETWEEN THE NORTHERN PACIFIC RAILROAD AND MISSOURI RIVER. ITS TOPOGRAPHY, CLIMATE, VEGETATION, IRRIGATION POSSIBILITIES AND COAL DEPOSITS

BY L. H. WOOD

INTRODUCTION

The area treated in this report lies in the extreme western part of the state, and comprises the river areas between the Northern Pacific railroad and the Missouri river. The parts more especially studied were the valleys of the following streams: The Little Missouri north of Medora; the lower ten miles of Beaver creek; the flats of Cherry creek in the vicinity of X ranch; Knife river and its tributary, Spring creek, and, lastly, Farmer's valley and Deep creek north of Taylor and Richardton. The two chief purposes of the work, the study of the problem of irrigation and the lignites with reference to their use in irrigation, naturally confined the attention of the party to the flats along the principal streams.

Plan of Work on the Little Missouri.—The lack of continuous roads along the river and the extreme roughness of the uplands made it necessary to plan the trip by boat. We learned at Medora that this scheme was considered impracticable, if not impossible. No one had ever made the trip in this way, and the reported drying up of the stream during the summer months to a series of pools of stagnant water, together with the record of the Missouri survey party, that the lower end of the Little Missouri had been seen dry, did not seem to warrant that the party would ever reach the mouth of the stream by boat. Whatever misgivings may have been entertained the experiences of the first two weeks were poorly calculated to remove. When the boat was loaded with the supplies it was found to draw twelve inches of water, or more than the average depth of the stream. By good fortune we were able to send the larger part of our baggage to the mouth of Beaver creek, where we arrived two weeks later after pulling, tugging and lifting the boat over long and frequent sandbars. Almost continuous wading was necessary over stretches of miles in length, and reaches where rowing was possible for more than a mile without encountering bars were rare. As a rule the channel follows the cut-bank, with a depth of two or three feet of water for a half mile or more, and then, in passing to the cut-bank on the opposite side, spreads out, fanlike, depositing its load of sediment along lines that frequently shift in a direction transverse to the flow of the stream. Very often the river divides into two nearly equal streams, one of which again subdivides into parts further down the flank of the broad, flat sandbars, each minor stream making its way back to the undivided partner on the opposite side of the bar at the first opportunity. Again, both parts of the divided stream interlace in a maze of sandbars, making it almost impossible for the boatman to thread his way through the uncertain depth of water. But perhaps the most troublesome habit of the river was that of dividing about equally at the head of a bar a mile or more in length, one of the divisions having no outlet below. At such places a sluggish current, due to low water, made it frequently impossible to tell which was the living channel; and several times the party found itself in one of these pockets of stagnant water, from which the only outlet was a return to the head of the bar. The prevailing muddiness of the river made it necessary for one person to be continuously on duty at the bow of the boat, where, by striking out to the right or left with a long pole he was able to keep to the deeper part of the channel, which often became so narrow that the boat would pass only by being propelled from the rear.

The slightest weakening in the velocity of the heavily loaded stream was followed by a deposition of sediment at all parts of the channel, even when the water was high, and once the boat struck on a sandbar when the water a few feet away was from six to ten feet deep. Not the least of the dangers to which our course was subject in this fitful stream, were the narrows under the lee of the bluffs. At these points the river usually contracted to a width of but a few rods, while the channel was generally full of boulders of sandstone and coal through which the current ran swift and deep. At a few places concretions of ferruginous sandstone jutted out ridge-like into the stream, producing swift rapids with deep pools below them. At such points the only course was to shoot the rapids, where, in attempting to

Roosevelt's old ranch. twenty-eight miles below Medora. (His other ranch, from which his old cabin was removed to St. Louis for exhibition purposes, was situated above Medora)

avoid catching on the reefs of sandstone, we ran the risk of capsizing on sunken rocks.

On the whole, the river did not give us the trouble from lack of water that the experience of the first few days had led us to expect. Even where the channel was but a few inches deep there was generally a strong current that greatly facilitated dragging the boat over many long reaches where it would not float. Running water was found over the entire distance, and due to opportune showers the depth of water increased after the first few days out, so that by the time Beaver creek was reached there was an abundance. Two weeks later, or about the 20th of July, the stream was again running very low, rendering progress somewhat slow for the last sixty miles of our course. But on the 22nd and 23rd of July heavy showers occurred that raised the river five feet in one night, and carried us out to the Missouri in from ten to twenty feet of water where we had expected to find dry land.

The plan of work followed along the stream was determined by conditions encountered. During the forenoons the party was divided for a study of the creeks on either side of the river; while in the afternoon, this part of the day being chosen because wading was then more pleasant, all were kept busy in getting the boat further down the stream. In this manner a considerable portion of the country on each side of the stream was examined by the members of the party. Where the nature of areas closely related to the Little Missouri valley seemed to invite it, several longer excursions were undertaken to the right or left of the stream. Beaver creek was visited ten miles above its mouth; the widest part of the bad lands, in the vicinity of Roosevelt's old ranch, was penetrated some ten miles or more, by one of the party; the Yellowstone divide below Beaver creek was reached; a considerable part of the area called Cherry flats was seen; and one day was spent in the study of the Kildeer mountains. Also, while making the trip in the Knife river valley, the Little Missouri country was again approached and visited at the head of Magpie creek at the Simpson ranch, and again on Hans creek below the Anderson ranch.

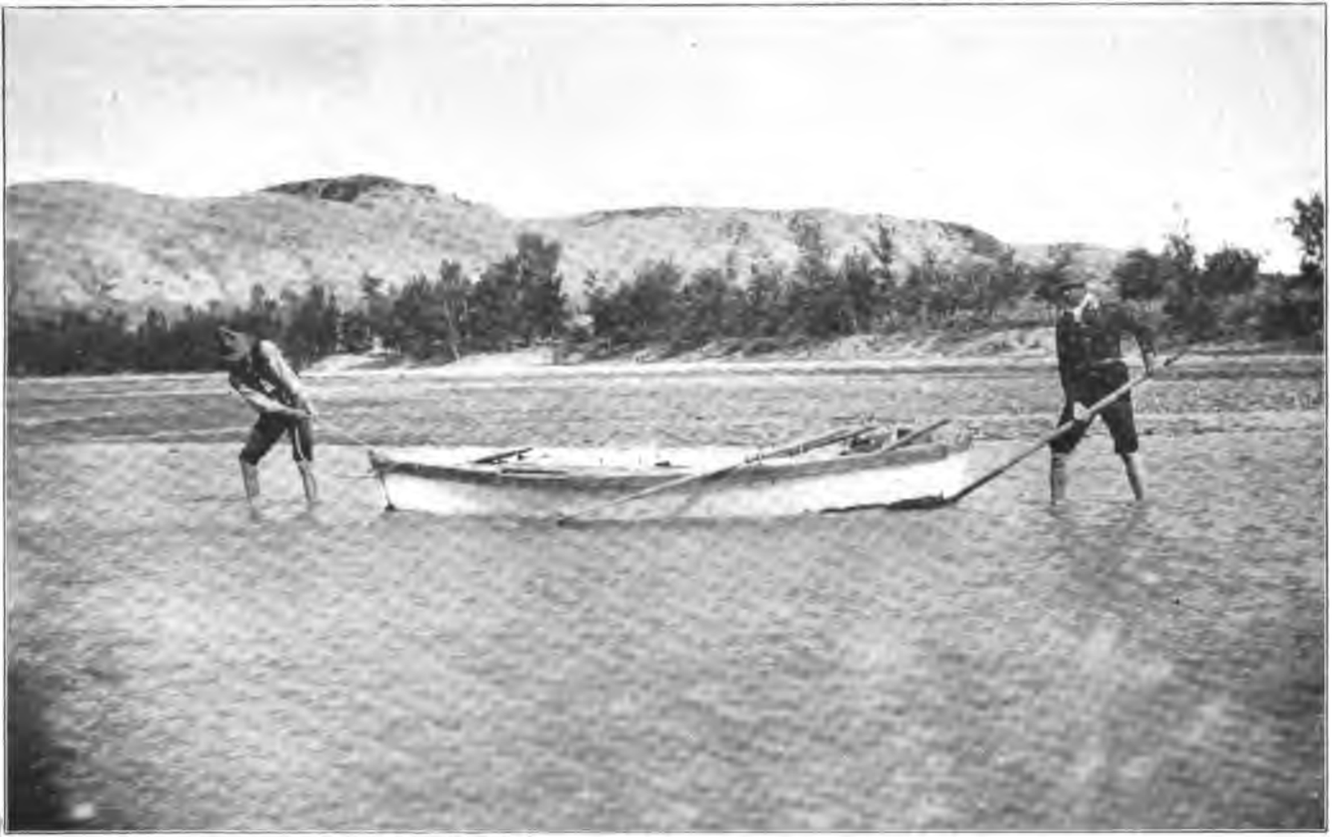
Work on Knife River.—For this part of the work preparations were made at Mannhaven July 29th and from this place the party set out by wagon toward the south and west. Knife river was struck three miles below Hazen and followed to the mouth of

Spring creek, whence the route led along the creek to Halliday and Oakdale; then southwest by the headwaters of the Little Knife, and east to Fayette; from Fayette the course followed passed to the head of Knife river, over the divide to the head of Magpie creek, again south and east to Dickinson, Gladstone and Taylor; thence by the way of Farmer's valley and Deep creek to Rock Spring on the Knife river. From Rock Spring a trip was made up Crooked creek to study the flats along the lower course of that stream. Starting east from Rock Spring the valley of Knife river was followed continuously to a point eight miles below Hazen, where the trail to Mannhaven was again taken up.

The Survey was fortunate in securing the services of Mr. Pease and Mr. Goodall, students from the University of North Dakota; the former rendering excellent service through his intimate and accurate knowledge of the trails of the region, the latter by his painstaking care in making the photographs of the area. Both took no small part in working out the details of the hydrographic and physiographic problems of the region.

The pages that follow are given to a consideration of the topography of the area, to roads, settlements, possibilities for agriculture, irrigation and accessibility of the coal lands. The climate of western North Dakota is considered with reference to agriculture and stock raising, and a brief notice is taken of crops adapted to the region. A few special problems, such as conditions under which the coal was formed, effect of the drift and problems of valley formation, herein briefly discussed, would, it is believed, richly reward further studies undertaken purely from the scientific side.

It is necessary to say for the map which accompanies this report that it is not intended to represent exactly the topography found in any one small part of the area, but to give a general idea of the surface in respect to relative elevation, roughness, breaks as compared with flats, position of coal outcrops and the location of the more significant features. With respect to localities it is believed that the map is fairly accurate since, so far as possible, town, range and section were considered in the preparation. No maps yet made of the area are found to be accurate, and for the Little Missouri region no exact map can be made, since much of the area is yet unsurveyed. So, while the map cannot be used as a road guide, it is hoped that it may convey to



Difficulties on the Little Missouri

the person interested in the region some better idea of it than could be obtained from the ordinary map. It is constructed roughly as to scale of elevation, the basis being the height of the area with reference to the Missouri river at Bismarck.

CULTURE.

Under this heading are included the following subjects: Area compared with eastern North Dakota; location of dwellings; farming and grazing areas; roads and trails; post-offices.

The one thing that most impresses itself upon the tourist in eastern North Dakota is the openness of view out over countless acres of broad prairie. The houses, with their small patches of sheltering copse, stand out conspicuously on the plains, with nothing but waiving fields of grain to hide them from view. Along the Red River, for forty or fifty miles on either side, farm lands, as level as a lawn, stretch out in the distance as far as eye can see, dotted with houses which seem to be as uniformly placed as the township lines; and with no fences, or hedgerows, or hillocks to intercept the view, one feels that he is upon a sea of land. At night, in the autumn, one may see the blaze of a dozen burning straw stacks lighting up the horizon. Yet here the population is not dense, for many a section goes untilled, and many more are but imperfectly cultivated. Nature has blessed the land with the richest of soil. The contrast between this area and the Little Missouri country is sharp. No houses are seen on the uplands bordering the valley. In every direction dry, sunburned grass lands and barefaced clay buttes alone relieve the monotonous upland plains. As one scans the horizon, viewing some especially broken part of the bad lands, not a living thing is visible as far as eye can penetrate the maze of yellow and gray, clay buttes; nothing but sunburned grass, bare, steep-faced gorges and red, burned clay met the gaze in every direction. Miles of broken land stretch between the scattered dwellings of the ranchers; for sites for buildings are not determined by section lines, but rather by the irregular placement of the valleys where shelter may be obtained. Where the uplands are flat, extensive grazing lands replace the waving grain fields of the eastern half of the state. The two regions, the one east and the other west of the coteau of the prairies, are sharply set off from each other, the former adapted to farming, the latter practically valueless except for the pasture afforded by the thousands of square miles of upland prairies.

In the region of the Little Missouri the valleys alone are occupied. On descending from the bad lands or the upland flats to the lower levels along the streams, the aspect changes decidedly. The life that has fled from the scorched and bare hillsides is found crowded along the water courses. Here forests of poplar, dense growths of shrubbery, birds, insects, wild beasts, and man himself have sought the protection afforded by the walls of the valley from both the scorching summer sun and the chilling northwest blasts of winter. Here is also found the water so necessary for the herds which graze on the plains above. It can be truly said that the life of the region clings to the ground water level, which lies, for the greater part of the year, several hundred feet below the upland plain.

Ranches are found at intervals of three or four miles along the Little Missouri, located either on the river side or at springs, some of which are miles from the main valley up along the creeks. Claims in the Little Missouri valley are held largely by squatters' rights and boundaries are not defined. The settler secures a good watering place, or a protected spot for his stock sheds, or, remote from the streams, a good spring, and the mere matter of acres of land is a thing that, so far, takes care of itself. In years past several points along the river were occupied by larger ranching companies, such as the W, the X, the Diamond C, and very large herds of cattle were gathered upon the grazing lands; but at the present time, due to reverses and to overfeeding on the grass lands, the larger companies have either left the region, or are represented by small holdings only. Along some reaches of the river smaller ranches are placed somewhat too frequently at the present time to suit the demands of grazing, and due to the crowding in of new settlers the danger of overfeeding and consequent destruction of native grasses is imminent. Some system of supplementing the natural resources of the hay and grass lands is badly needed, and especially a more systematic apportionment of the grazing lands.

Holdings along the valley of Knife river and Spring creek are obtained by purchase or by homesteading. Several claims here cover more than 2,000 acres, besides the use of the unoccupied adjacent grasslands. Some of these holdings include lands along the creeks, which a system of irrigation will make very valuable. The lower courses of the stream above mentioned, in the vicinity of Hazen and Stanton, and the adjacent uplands near Krem and Mannhaven are much more fully occupied. Around Krem some excellent crops are raised by a system of dry farming which the Germans of this area practice with great success. There is probably much more land southwest of Krem that is adapted to this sort of farming. The area in question is that over which the glacial ice has passed, the natural clays having been mixed and made far more porous, and thus capable of absorbing and holding the rainfall for a greater length of time than the impervious clays of other parts. This capacity to hold the moisture for some length of time makes it possible for the growing plant to use the part not lost by evaporation.

Several good farms were noticed in Farmer's valley, and also on the more sandy uplands north of Dickinson and Gladstone. It seems not unlikely that small areas will be found, even along the uplands of the Little Missouri, where dry farming would yield good crops two or three years out of five. The annual rainfall, though small, comes largely in the growing season, as will be shown later, and crops which get a good start have a fair chance of coming to maturity.

Dwellings.—The finest buildings in this area, outside of the towns along the Northern Pacific railroad, are those of the German settlement in the vicinity of Mannhaven. Here the sod houses of the earlier settlers have given place to well built farm houses one and two stories high. There are also large, well kept barns and substantial sheds for stock. Two churches stand out conspicuously in this locality, the only ones seen north of the railroad, forming sightly landmarks visible for many miles around. Several local stores supply the immediate wants of the farmers. Along Knife river and Spring creek the dwellings are also of a substantial sort, built mostly of lumber hauled from towns on the Northern Pacific railroad. They are usually of one story, since that is found to be the best form to weather the severe winters; and they are generally placed in some well protected part of the valley and screened more or less by low spreading box elders and white ash. It is along the more inaccessible Little Missouri that the houses retire into the more primitive class. Here lumber is scarce, the nearest towns are fifty or sixty miles away, and the roads are very poor. As in other areas the ranchers want the best, and are able to have it, but so far low, one-story log houses are found to meet all the requirements of comfort. Protection for stock is found in the draws and timber land along the river rather than in large and well kept sheds. Houses for both man and beast are largely extemporized. Poplar and red cedar is abundant, so that many of the buildings are constructed of these materials. The sheds are constructed of these materials. The sheds are built in the fashion of a stockade, part of which is roofed over with a capping of bushes and hay. The houses are substantially built from logs; either in the fashion of an ordinary log house, or with logs set on end to form the side walls, which are afterward made tight by a plaster of gumbo. The roofs are of various sorts, some of shingles, others of dressed cedar logs covered with burned clay, and still others buried under a layer of earth. While the use of much undressed material gives the house rather a rough exterior, the inside often presents a cosy, inviting appearance, with furnishings adapted to the needs of ranch life.

But one school house was seen in all this region, and this was the property of a few enterprising ranchers living below Rock Spring. This small building, dismantled of its furnishings, is now on the land of Mr. Paulson. The ranchers with families live so far apart that it is cheaper to send children to school at towns along the railroad than to hire a teacher.

Roads.—The roads most traveled are the mail routes from towns on the Northern Pacific railroad to the postoffices of Knife basin, Hazen, Broncho, Halliday, Rock Spring and Oakdale. Roads from these places, with connecting cross trails, run to Hebron, Taylor and Dickinson. Branching off from these roads, trails extend along the valleys from east to west to ranchers more remote from the mail routes.

The postoffices are subordinate centers from which roads and broncho trails extend in many directions. The mail routes, together with the more traveled roads, make it possible to get to most parts of the region with light rigs or on horseback, but the hauling of large loads is a serious matter. Bridges are rare, and crossings good at one season may be washouts at another, where mud makes the roads impassible. It is not an uncommon thing for a man to be obliged to unload his wagon and transfer it by peices from one side to the other of a bog that has developed in the roadway. The steep hills along the streams with the sharp pitches at the creeks need much grading before some parts of the region can become readily accessible. The hills of the Little Missouri valley are especially steep, and the narrow branches along the creek valleys where the roads must pass are most liable to washouts.

The principal trails are indicated on the map which accompanies the report. While they are not correct when compared with section lines, they serve to indicate the general direction along which one may find his way to various parts of the region.

TOPOGRAPHY

General.—The region presents two general types of relief. One of these types, the bad lands, is in the main driftless and coincides for the most part with the Little Missouri basin south and southwest of the Indian Reservation; the other, included within the basin of the Knife river, has had its surface greatly modified by ice action. Neither area, however, is at all uniform either in respect to bad land distribution or to modification by the ice; for both areas have bad lands and both have been affected, but to different degrees, by the results of ice action. The contrast is, nevertheless, very decided, and is strikingly portrayed to one viewing the two areas from the top of the Kildeer mountains at Oakdale. From this point, which is five hundred feet above all the surrounding country, one looks out and down upon the plains, and is able to distinguish outlines of relief sixty miles away. A line running from the southwest corner of the Indian Reservation to the Kildeers, and from there to Taylor, may be taken as the division between the two types of typography mentioned above. To the east of this line the entire area is more or less broken, being about equally divided between low hills of irregular outline, and rather wide basin shaped valleys. A glance to the southwest shows what was once a broad plain extending at a uniform level as far as eye can see. Here and there upon this surface a low hillock rises perhaps a hundred feet above its surroundings and marks the position of what was formerly a stately butte, its summit high above the surrounding level, now crumpled and wasted away to but a mound upon the plain. Farther to the west and south the basin of the Little Missouri is hemmed in by a more lofty wall of buttes that crowns the divides on either side of the valley. This broad upland plain lies at a level five hundred feet below the top of the Kildeers, which rises wall like on its eastern margin. Down 600 feet below the surface of the plain is the channel of the Little Missouri; and at irregular intervals along its course the plain breaks away into singularly patchy groups of pyramidal hills whose tops lie, for the most part, a little below the level of the grassy upland plain from which they have been carved by the torrential rains. These groups of buttes, gray, yellow and white, remarkably uniform in shape and size, stand out in strong contrast to the dark brown and green plats of vegetation that hem them in on every side.

The striking features of the topography are the wide stretches of upland flats, the deep valleys of the streams, and the breaks along the courses of the creeks. While the topography here is more sharply defined, and its parts more strongly contrasted, it is much less complex than that east of the Kildeers. Along the Little Missouri there is much very flat upland with the same general level; while along the Knife low rounded hills and broad valleys occupy most of the surface, and the barefaced buttes so common on the west, are less often seen in the larger part of the Knife and Spring creek basins. The valleys of the streams are also greatly unlike, (see figure 1) for those of the Little Missouri region are broadly U shaped with extremely steep slopes, while high bluffs are generally absent from the valleys of the streams at the east.

The area to the east of the Kildeers was doubtless not unlike that of the Little Missouri basin in preglacial days. Now its steep slopes have been greatly toned down, and its flat, upland surface roughened by ice action. In some parts it seems to be a tumultuous sea of hills, with an entire lack of uniformity, either of size or manner of placement, so that the area presents a typography of peculiar type, and though with less relief, it appears, in the distance at least, to have a rougher surface than lands on the west.

In elevation, likewise, the two areas are somewhat in contrast. The country east of the Kildeers rises gradually from an elevation of 2,200 feet at the Missouri to 2,500 at Oakdale; while the Little Missouri valley maintains for the most part along the river an elevation of 2,500 feet, so that the stream channel lies much more below the level upland northeast of the Killdeers than at Medora, bluffs at the former location being about 550 feet above the river, and 250 to 300 feet at the latter. In both areas the elevation falls off rapidly within the margin of the drift.

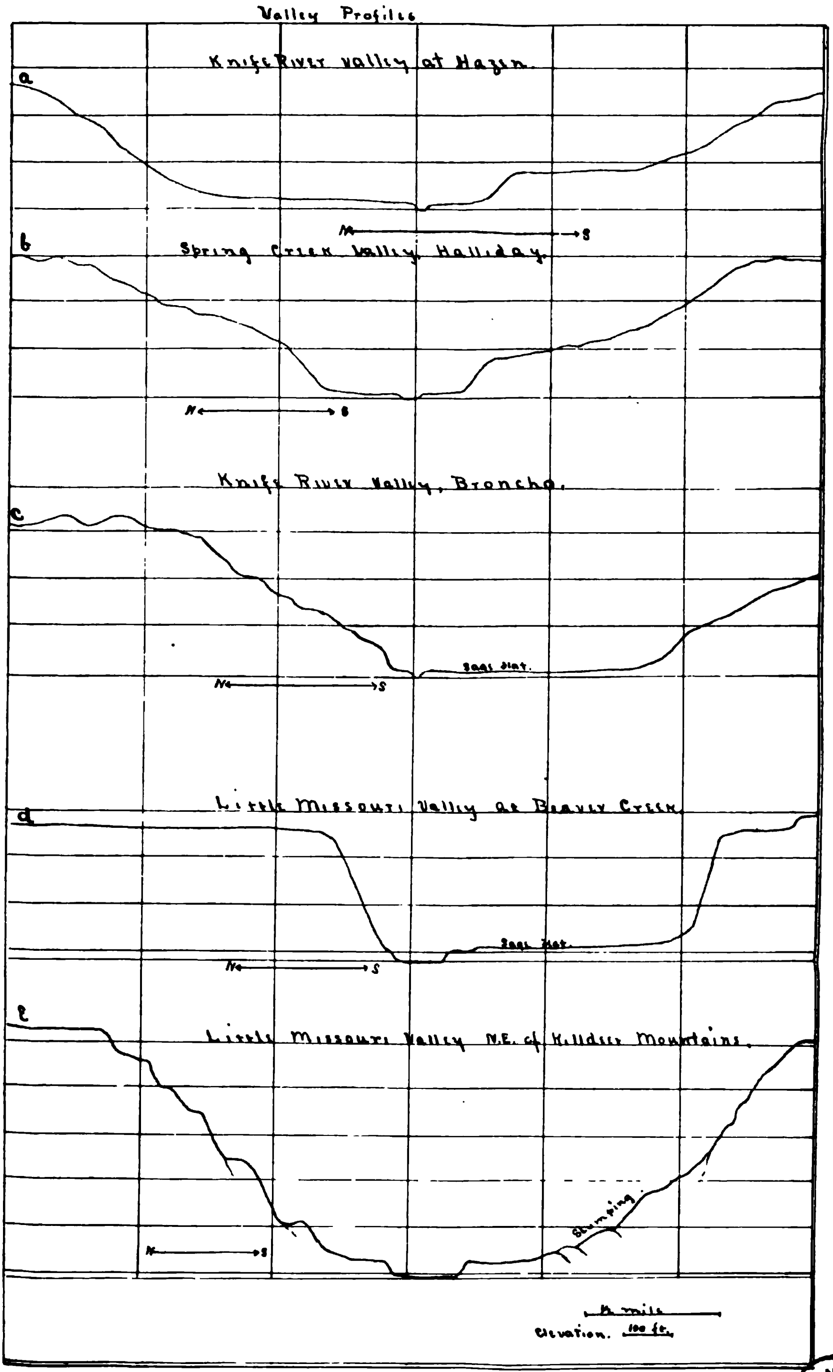

Valley Profiles
a
Knife River valley at Hazen.
N
S
b
Spring Creek Valley Halliday.
N
S
c
Knife River Valley, Broncho.
Sage flat.
N
S
d
Little Missouri Valley at Beaver Creek.
Sage flat.
N
S
e
Little Missouri Valley N.E. of Killdeer Mountains.
Slumping.
N
S
½ mile
Elevation. 100 ft.

Fig. 1. Valley profiles

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TOPOGRAPHY OF THE LITTLE MISSOURI REGION

Valleys. The valley of the Little Missouri, as well as those of its tributaries, is broadly U-shaped. Since the valley is the product of a long erosion period we should expect to find the uplands grading off to the level of the stream by gentle slopes. Such is not the case, however, for the aridity of the climate has entered as a large factor in the erosion history of the whole region, with the result that the cutting due to lateral work has been reduced almost to zero. The slopes of the stream rise abruptly from the terraced floor of the valley, at an angle so sharp in many cases that the bluffs cannot be climbed; and the effect of these slopes, rising like two walls on either side of the stream, is to set it off sharply from the broad, flat upland plain. From Medora to the Missouri the valley is not unlike a great trench, with steep faces and a broad, flat bottom cut in a level plain. In width the Little Missouri valley averages three-fourths of a mile, ranging from a half mile to a mile and a half from bluff to bluff. The walls rise 300 feet above the upper flood plain at Medora, gradually increasing in relative height to a point north of the Kildeers, where the upland level is 550 feet above the river. The flats vary in elevation above the stream from a few inches to forty feet.

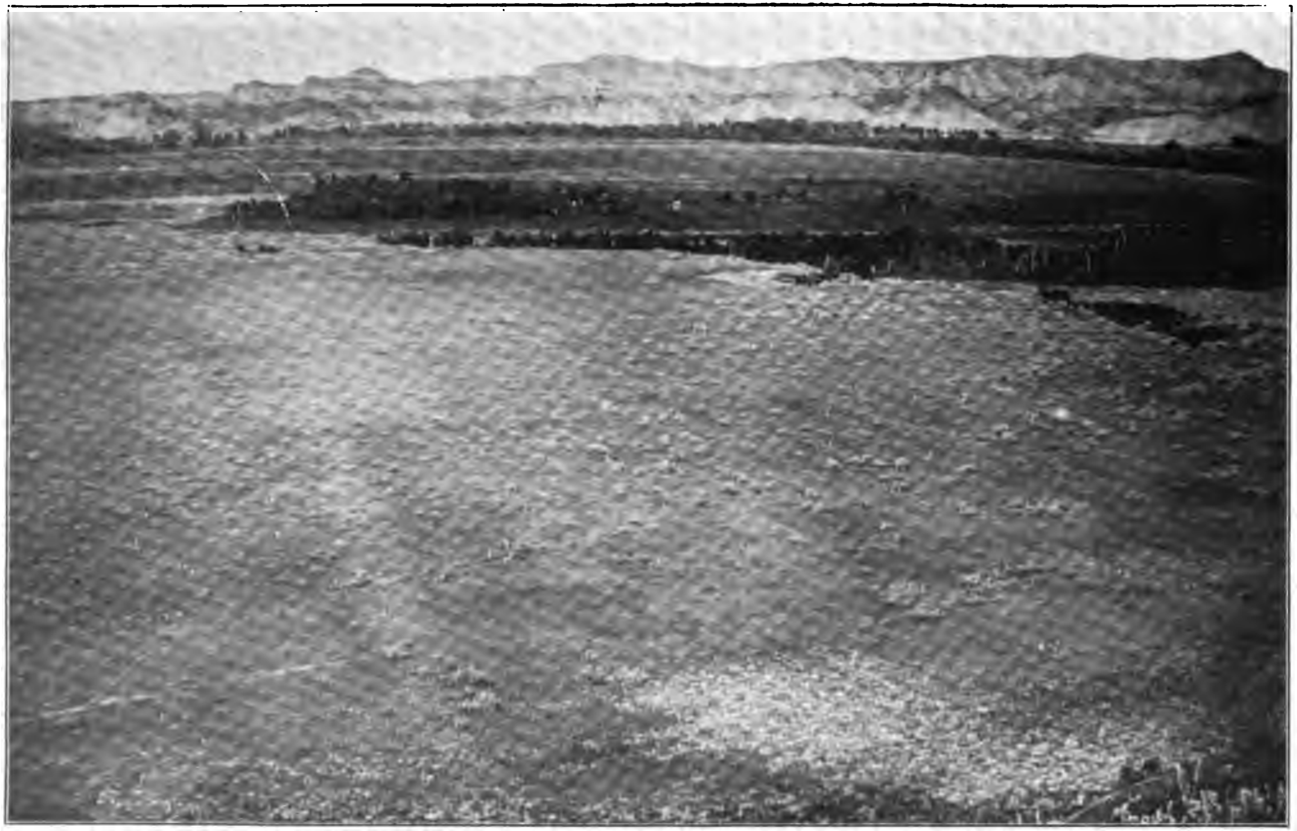
Sage Flats. This term is applied to flats that lie in general about twenty feet above the river. They are usually sage covered, without forests or trees except for the margin of shade along the river, and have a remarkably smooth surface that slopes gradually from the buttes in the rear down to the river where they usually terminate in a vertical cut bank.

Wooded Flats. The flats lower than the sage flats above mentioned are mostly covered with forests of cottonwood and with bushes. They have an irregular surface due to the presence of remnants of the old channels of the river and are prevailingly sandy, which further unfits them for cultivation. In many places freshly blown dune sand is contesting with plants the right of way on these flats. Their margins are inundated at higher floods, while the streams are in many places cutting laterally into their margins, removing material for deposition elsewhere. The progress of the river cutting is somewhat retarded at many points by the rapid growth of willows, whose roots, ever seeking more water, reach far forward in the bed of the stream during the dryer parts of the year.

Bars. In the very bottom of the valley, the lowest flats, but a few inches above the water level, are found at all parts of the channel, but generally have their greatest development on the opposite side of the cut bank. They are simply the temporary shoal of high water, and represent the momentary weakening of the currents that carried the materials. They are resting stages of the sands on their way to a more permanent abode in the Gulf of Mexico. In shape these bars are most interesting. The longer ones stretch for a mile or two down the stream, either unbroken or cut into many islands by the network of narrow streams that flow diagonally across them. A series of these longer bars, crossed and recrossed by the stream, may extend for miles along the channel in low water. Other flats are fan-shaped, and vary in form with the strength of the current. Still other bars, crescent in form, hem in the current at every curve of the stream; these will in time be covered with cottonwoods and join the rank of river terraces.

So abundant are the fine sands of the valley that the stream at low water is often so obstructed for many miles at a stretch that it is virtually cut into a series of long, shallow basins connected with each other by short rapids where the water is but a few inches deep. So quiet was the water in some of the basins that where the stream was divided by a medial bar it was often difficult to tell which channel led out below at the lower end of the bar a half mile or more down the stream.

Size of the Channel and Depth of Water.—The channel of the river varies greatly in width between high and low water. At high water it is from forty to sixty rods wide, while during the most of the time its wider places, at the fords, are ten to fifteen rods.. The depth of water in the channel varies in a general way with the velocity of the current. The reason for this fact is that the bottom of the river is covered with loose, uniformly fine-grained materials, all of which can be readily picked up and carried forward by moderate currents. Increasing the velocity relatively diminishes the load, and more materials will be picked up and the water consequently deepened. A very interesting result of this effect is the unusual deepening of the stream in high water. In periods of low water much of the sediment is laid down over the bottom of the channel uniformly, in many places to a depth of two or three feet. At high water this will be picked up, and while the surface of the river is rising three or



An upland flat in the foreground; a sage flat bounded by the Little Missouri in the rear. Near the ranch of J. C. Morgan, three miles above the mouth of Beaver creek

Level uplands in the vicinity of Beaver creek. Upland surface covered with coarse gravels

four feet the deepening due to the removal of the materials from the bottom nearly doubles the increase in depth due to the rise of the water. This deepening holds for the Missouri, as well as for its smaller sister valley, and the effect produced on the appearance of the current is striking. In both streams in high water the current does not flow smoothly, but, meeting with this great mass of sediment along the bottom of the channel, the current seems to be checked and deflected laterally and upward in its struggle with the sands which persist in tumbling downward toward the bottom, with the result that the surface is thrown into great heaving, whirlpool-like areas which advance continually down the stream. It is as if the current were continually stubbing its toes on the piles of sand at the bottom of the stream, and, after a sprawling somersault, as continuously recovering itself at the surface of the river. It is through this choking of the current by the fine materials that so much sediment is carried forward by the stream, and hence in high water it appears not unlike a stream of mud.

Upper Terraces.—At an elevation of from 150 to 250 feet, benches are found at several different levels, having an area in some places of many square miles. At Medora, these upland benches have flat surfaces and lie at elevations of 140, 160 and 180 feet respectively. Five miles north of Medora, upland flats were observed at levels of 120, 160, 190, 200, 220, 240, 255 and 310 feet above the river level. Above Beaver creek, flats, several in number, were observed above the level of 200 feet. All of the upland flats mentioned above were surfaced with gravels and coarse materials consisting of chert, quartzite and some material of igneous origin. In some cases the depth of such material was several feet. Its presence on the upland levels renders the soil porous, so that it holds the water which falls upon it, enabling it to support an abundant growth of grass by which it resists both water and wind erosion. Good views of these grassy upland benches are shown in plates X and XI.

Tributary Valleys.—The main valley of the river branches little in comparison with those of a humid climate. This again is a characteristic due to aridity; for, while many gulches have been started, there has been too little erosion in the present cycle of the stream to permit many of the gulches to grow into long valleys. The walls of the valley are broken through in many places, however, by ravines and gulches, and by the waters of a few large creeks. The valleys of these large creeks simply repeat the characteristics of the master stream, even having, along the lower part of their courses wide, flat bottom-lands. Beaver creek valley is nearly as wide as that of the river, and several of the other creeks have valleys a half mile wide for the lower two or three miles of their course. It is likely that these larger creeks represent cutting in more than the present cycle, having originated when the river was working at some former level.

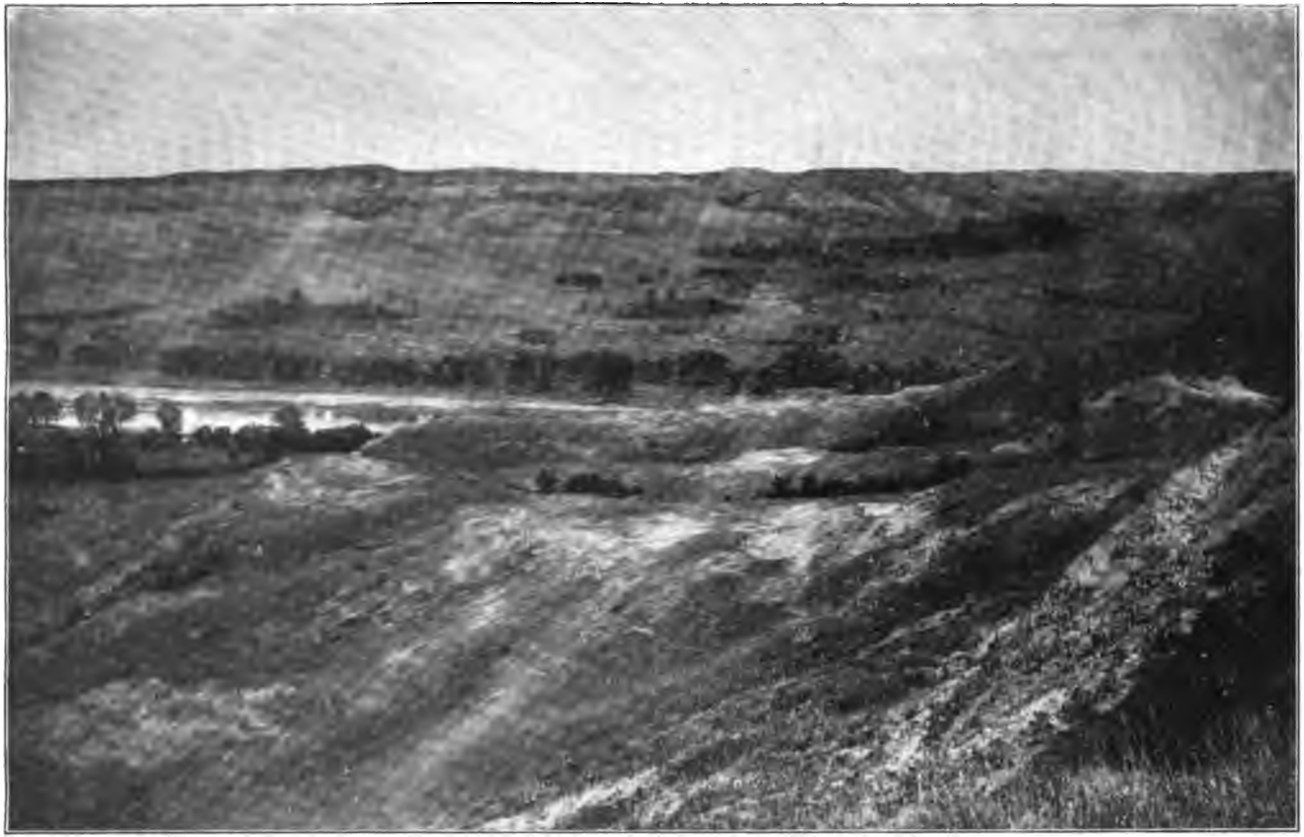
The gulches, ravines and creek valleys greatly dissect the belt of two or three miles on either side of the river, making travel along the uplands bounding the stream absolutely impossible. Roads pass up the longer creeks until an easy ascent can be made to the upland flat, where the trail continues to the head of the next creek valley from which the approach can be made to the river crossing. A trail extends from Medora to the mouth of Beaver creek, following the valley. Below this point trails lead away from the river in the direction of some one of the several trading points — Williston, Dickinson, Fayette or Wibeaux.

BAD LANDS

Distribution.—The bad lands of the Little Missouri country are in every case distributed in close relation to the river or its tributaries, and since the creeks occur irregularly the bad lands are similarly placed. The "brakes," or bad land areas, assume a great variety of shapes, which are also dependent upon the form in which the creeks branch out. Generally the oval type of area is found near the head of creeks, while the lower course is faced with a belt of buttes two or three deep only. Again, very short creeks or draws head but a few hundred yards back from the main stream. The river itself is walled in on both sides, from Medora to the mouth, by buttes ranging from 200 to 600 feet in height. In passing from the floor of the valley to the uplands, either by scaling the steep faces of the buttes, or by making a detour to the rear along one of the short draws, one generally passes out onto a flat upland. Where two creeks with nearly parallel courses, not remotely separated, divide an area between them the bad lands may become very extensive.

Effect of Older Base Levels.—There is another condition that adds greatly to the complexity of these areas described above. The region plainly shows two base levels, and a sug-

PLATE XII



View looking up Blacktail creek, three miles south of the mouth of Beaver creek

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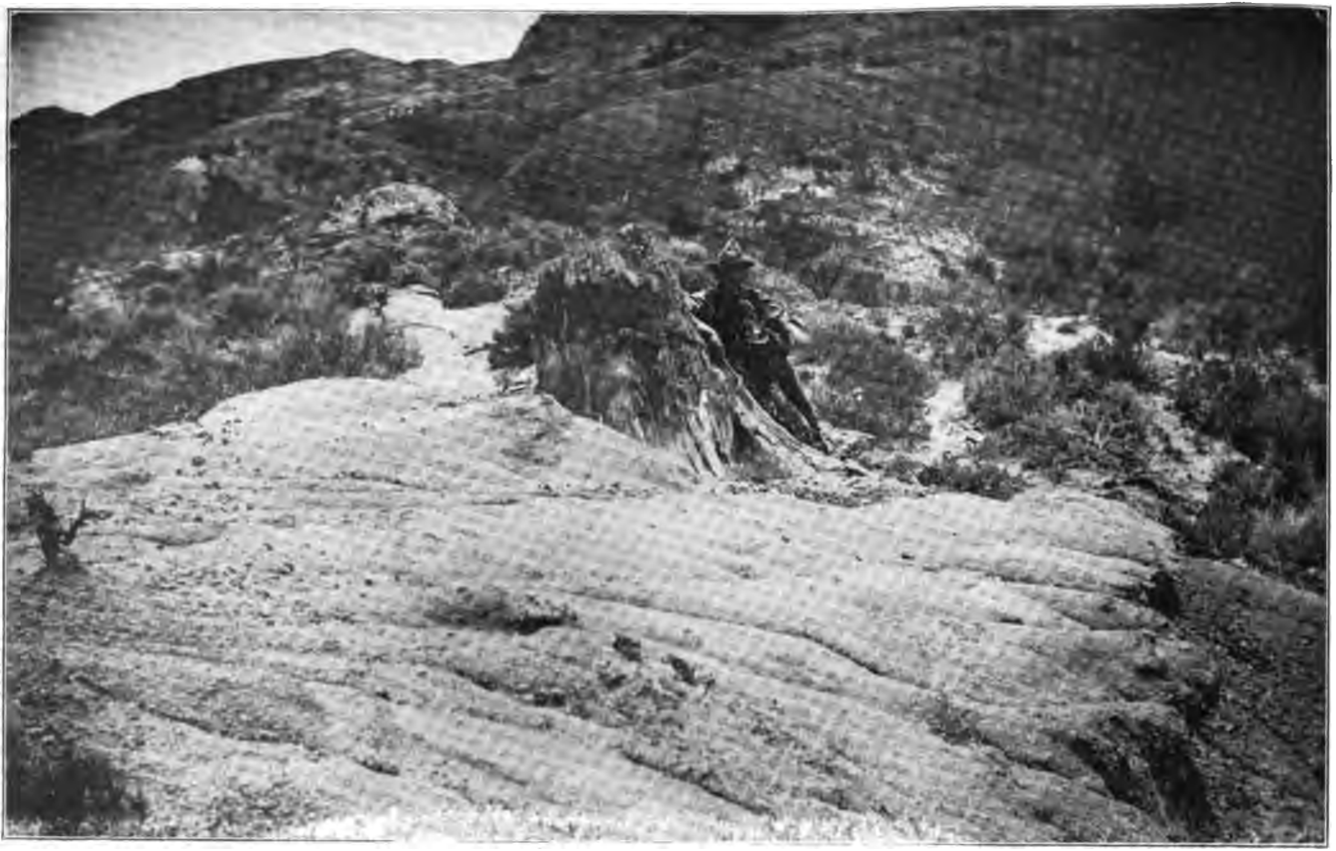
gestion of a third. The low, mound-like remnants of buttes dotting the plains here and there suggest a former elevation several hundred feet higher than the present level; in fact, portions of these old levels remain. They are represented by small areas only, as for example the Kildeer mountains, and the part of the divide in the vicinity of Fryburg; also the higher buttes that may be seen along the divides. Sentinel Butte is a remnant of a time long past when the areas had a level 600 or 700 feet higher than at present. These remnants of the former base levels are very deeply dissected, and stand out conspicuously above those of the present cycle. It is through a portion of such an area that one passes in riding from Fryburg down to Medora. When a stream or creek, cutting in the present cycle, works back into the field of one of these more ancient bad land masses, the surface becomes far rougher and more complex. This fact, i. e., the carving of buttes and bluffs from so many different levels, is the one that makes the topography so excessively rough in parts of the region. When one has scaled the steep walls of one level, he immediately encounters a more formidable array of still steeper slopes. From the summit of these hills one looks away from the stream in the direction of the divides and sees the same types repeating themselves until lost to view in the distance; while in the direction of the river one level gives way to another until the bare faces of the bluffs, walling in the stream, offer the last sharp descent to the flats in the valley below. Such an area as this may be seen east of Morgan's ranch along the division bounding Black Tail and White Tail creeks (Plate No. XII.), or east of the old Roosevelt lodge, eight miles below Mikkleson; in fact bad lands persist almost contintinuously from Medora to the mouth of Beaver creek on the east side of the river. This seems to be the most extensive bad land area of the region. Bounded on the east by the divide north of Fryburg, which has an elevation of some 500 feet above Medora, this mass of bad lands extends with a width of fifteen to twenty-five miles continuously from the Northern Pacific railroad to Maple creek, about thirty miles to the north; here it breaks away into a strip of rough, rolling upland, bounded on the Little Missouri side by a strip of bad land several miles wide.

Valley of Government Creek.—One point ten miles north of Medora at the head of Government creek presented some striking features. The basin of the creek was approached from the west by a very sharp descent from the divide between itself and the Little Missouri. From the top of this divide one sees, extending far to the eastward, an oval, ampitheatre-like valley whose general level is from 100 to 150 feet below the rim of buttes in every side. This whole basin-like area was apparently the watershed for Government creek. Near the center of the valley a lone butte lifted its summit to a level with the rim surrounding the valley. From this point one gets a view of the valley and the highland to the east, north, south and west. The low, round, dumpy, red-topped clay buttes of the valley surround the massive butte in the center and continue on to the east, a tumbling sea of irregular forms, gradually rising in elevation until they merge with the plains several miles to the eastward. On the north, one long, continuous ridge bounds the valley. Far to the southwest, Sentinel and Square buttes are still visible, along with another very large butte in the northwest. In this valley, depressed so distinctly below its surroundings, we evidently have erosion forms of a later cycle imposed upon the remnants of an older and higher base level. Not the least striking feature of this valley is the great extent of burned clay. Most of the low buttes are red-topped and often capped with sandstone, which has assumed a jointed, columnar, structure; or, in some cases, it is fused into a conglomerate mass, due to the effect of heat arising from the burning coal beds beneath.

The Effect of Burning Lignite.—The agent that effected this widespread change in the clays and the sandstone is still at work on the area. At the west side of the valley a ten-foot coal seam outcrops at the head of a draw, and a mile further to the east is found burning. The effect of this burning is not only to lower the level over the area burned by the depth of the coal seam, but to loosen and rearrange all the material lying above the seam, by causing it to cave in, and also by fusing a large part of the more fusible material into scoriaceous masses of large size. These jagged, angular masses resist weathering and erosion, and remain in many parts of the area to add greatly to the roughness. The loosening of the material also makes possible an underground seepage along the level of the burned coal, and a further cracking and loosening of the surface from this cause. An acre or more at the edge of the burning coal was thus depressed below its surroundings. The buttes themselves at this point were being rapidly undermined by the burning of the lig-



A large tree of the Laramie forest. Materials of unequal hardness

nite. The great extent of burned clay throughout this whole region leads one to believe that the bad land erosion is aided in no small degree by these fires in the lignite. The burning of these seams of lignite goes on but slowly. The seam above referred to has been burning in this particular place since 1882, and yet but little more than an acre has been consumed. The coal burns slowly for the reason that the process goes on at a greater or less depth below the surface, and consequently in a somewhat smothered condition. Other beds were seen burning under conditions which indicate that but little progress has been made by the fire for several years. The valley above referred to contains from sixty to eighty square miles. If the fires which have burned the larger part of the coal at the present level in the area were burning in only a few points at the same time, the period necessary to cover the valley would certainly be several thousand years. But this period would be short compared with the time that these hills have been subject to the slow process of rain and erosion. Relatively, therefore, the effect of burning coal in reducing the area to the bad land conditions would be a rapid process.

FACTORS IN THE FORMATION OF THE BAD LANDS

The more important factors in the formation of the bad lands and the steep slopes of the valleys are the following:

1. Streams.
2. Torrential rainfall.
3. Vegetation.
4. Burning lignite.
5. Winds.

The conditions under which these factors work are as follows:

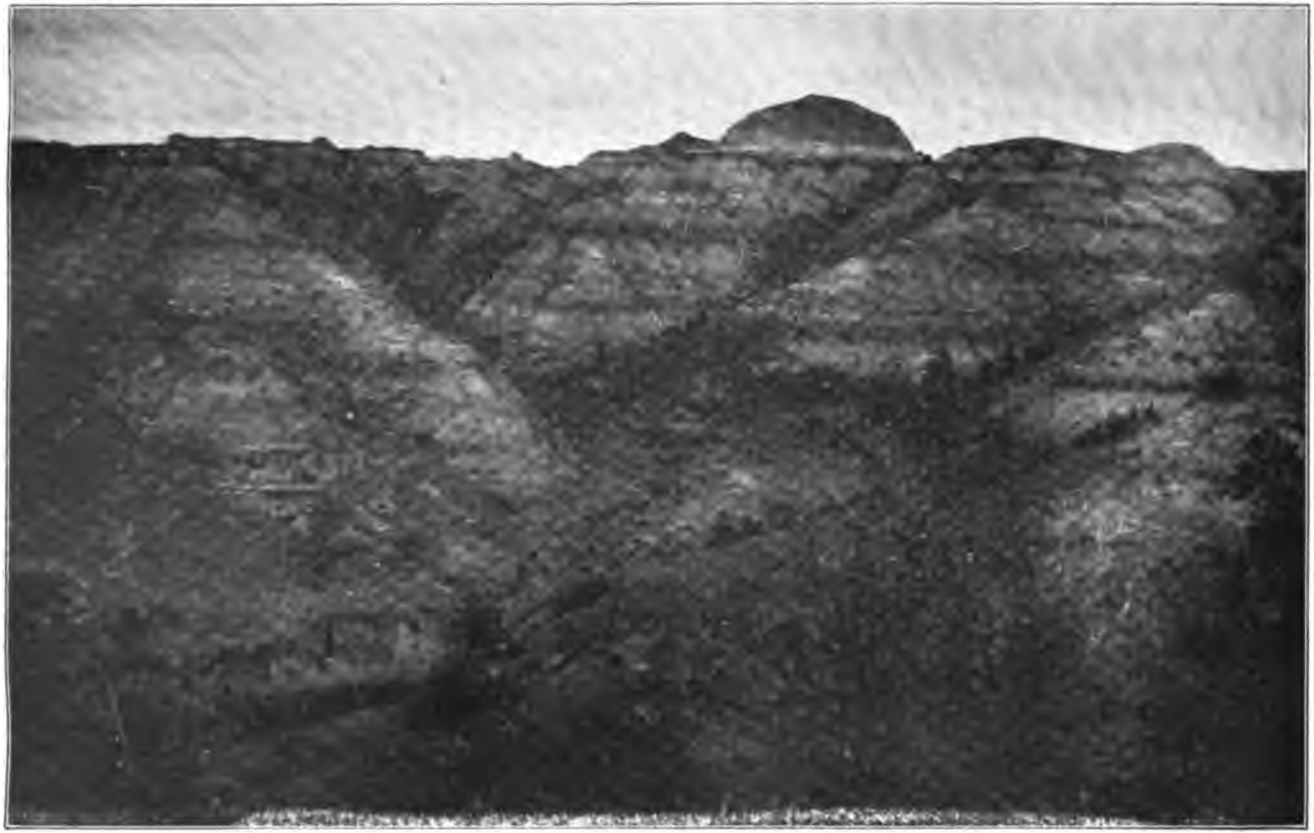
1. Arid climate.
2. Materials of rather uniformly fine texture.
3. Horizontally bedded materials.
4. The presence of irregular concretionary forms.

1. *Streams.*—Erosion in the bad lands is associated directly with stream action, as in any other region. Steep slopes can be formed only where ravines and gulches have developed. Slopes and run-off are inseparable. No depressions occur anywhere, except sloughs which are to be associated with the drift, that cannot be traced to the action of the streams. Streams are necessary agents in the removal of material that is washed down

the slopes, and serve to direct the course of the run-off. The first work on all groups of bad lands, then, began at the valley of the master stream, and the future of every gulch can be inferred from the forms seen along the ravines and creeks. Just as surely as the torrential rill is the parent of the creek, so the gulch formed by an afternoon shower is the ancestor of miles of impassible bad lands.

The river is at work all the time, the larger creeks part of the time and the small creeks occasionally, in transporting materials. Heavy showers temporarily overload the streams, but they accomplish their task by continuing to flow long after the showers have passed. Thus the valleys do not fill up and most of the debris of one shower is carried off before the next one occurs. The melting of spring snows supplies much water, but so gradually that the streams during this season are probably receiving less material than they can carry, and load up with materials deposited at other seasons.

2. *Torrential Rainfall and the Streams.*—Meteorogical observations show that not only does most of the rainfall of this region come during the months of May, June and July, but that the characteristic rains are thunder storms; these furnish much rain on small areas during short periods of time. Several times during the trip down the river, five or six distant thunderstorm centers were counted, hanging over restricted areas of the valley. The waters from these showers get rapidly into the stream, as was shown again and again by a raise in the river following immediately on the passing of the storm. Two series of showers occurred on the afternoons of the 21st and 22nd of July, both too far up the stream to give much rain at the point where the party was encamped; but as a result of these two storms the river rose about five feet, filling its channel from side to side with a deep, brown, muddy current that hurried swiftly by, carrying brushwood and all sorts of debris picked up from the flats. Thus it is that most of, the run-off, and the work accomplished by it, is concentrated into a very few hours. The steep slopes along the creeks are affected practically only while the storm lasts; the creeks carry much water for a few hours, and the river is swollen for sevaral days after the storm has passed. The river is kept at a more regular flow than the creeks, because showers are more uniformly distributed along its valley.



Bad Land topography near Blacktail creek. Remnant of former base level in the background

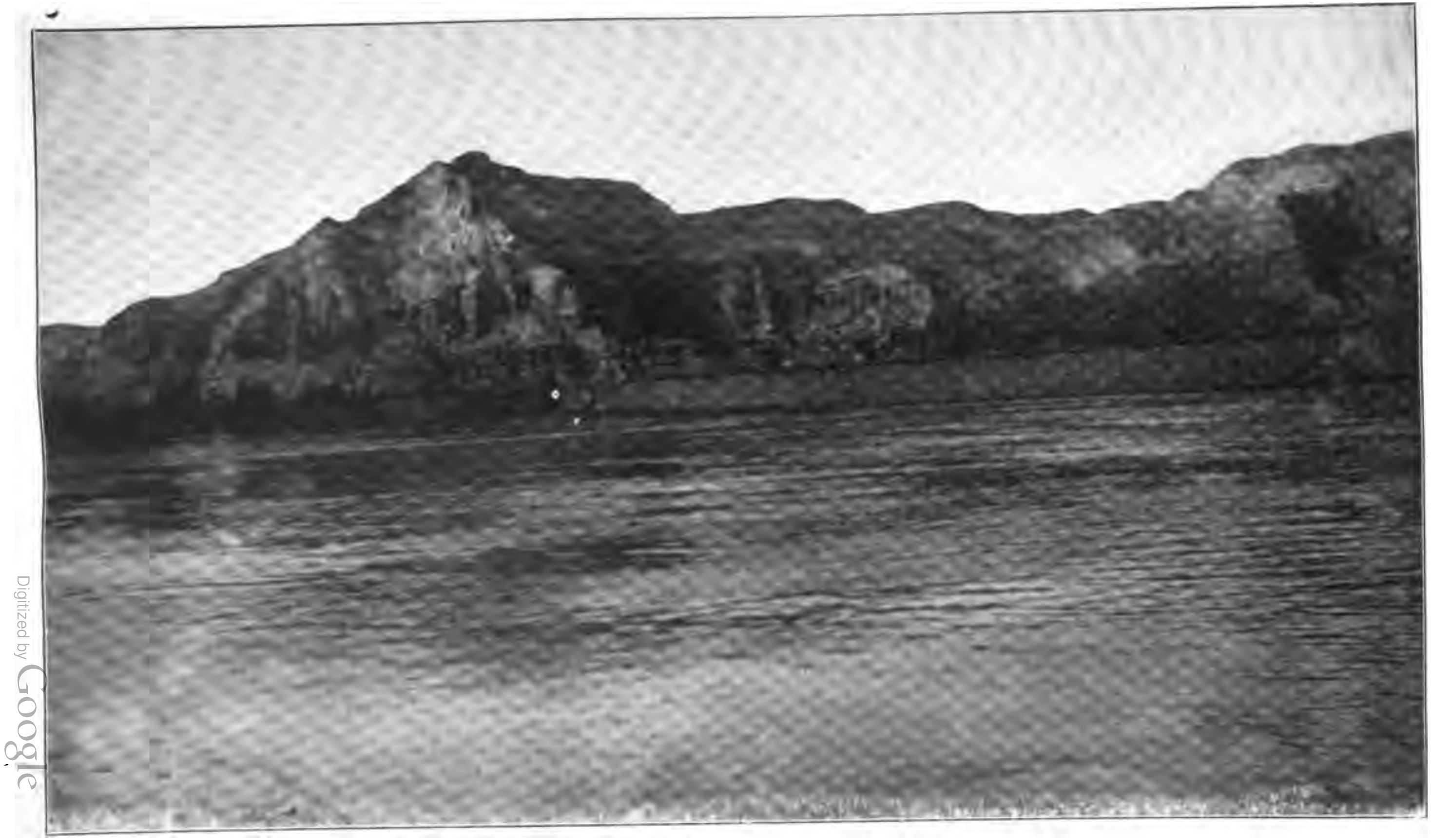
This specially irregular rainfall during the summer season is a matter not yet sufficiently recognized in the climatology of the area, and it seems probable that with an annual rainfall of fifteen inches, some parts of the area receive much less some years, and more others, than the average. The result of this peculiar distribution gives the river, with its long valley, a great advantage over any of its shorter tributaries in the work of valley corrasion; and by deepening its valley rapidly with reference to the creeks, steep gradients and consequent rapid cutting are the rule with them during the intermittent rainfall. It is very likely that some of the smaller creeks entirely escape heavy showers some years, and then have several during one year. The effect of this seems to be that the material accumulated in the valley by the more gradual processes of weathering is so distributed that the rapid flow due to torrential rainfall is not able to remove it all at once; but on the other hand, the torrent finding gradients steep and cutting in the loosened material easy, washes out a deep, trench-like valley through the debris. Such trenches, with vertical walls ten to thirty feet high, are very common all along the creek, and the materials are largely such as have slipped down from the steep slopes of the valleys. As a rule the creeks entrench themselves deeply below the surface of the alluvial fans and flats at their mouths. It is the presence of these numerous deep gorges of the lateral tribuaries of the river that makes traveling along the direction of the streams so difficult.

Torrential Rainfall and Erosion of the Slopes.—The lack of vegetation on the steep slopes due to intense sunlight, aridity, winds, and rapid weathering of the surface, and to a certain extent to lack of homogeneity in the rather weak materials, all contribute to make erosion by the occasional heavy downpours of rain extremely effective while the shower lasts. On the other hand, the long intervals between showers, the small amount of seepage, and practically no solution, tends to give an unusual permanency and stability to the bad land forms. Erosion is largely limited to the lines along which the waters are concentrated.

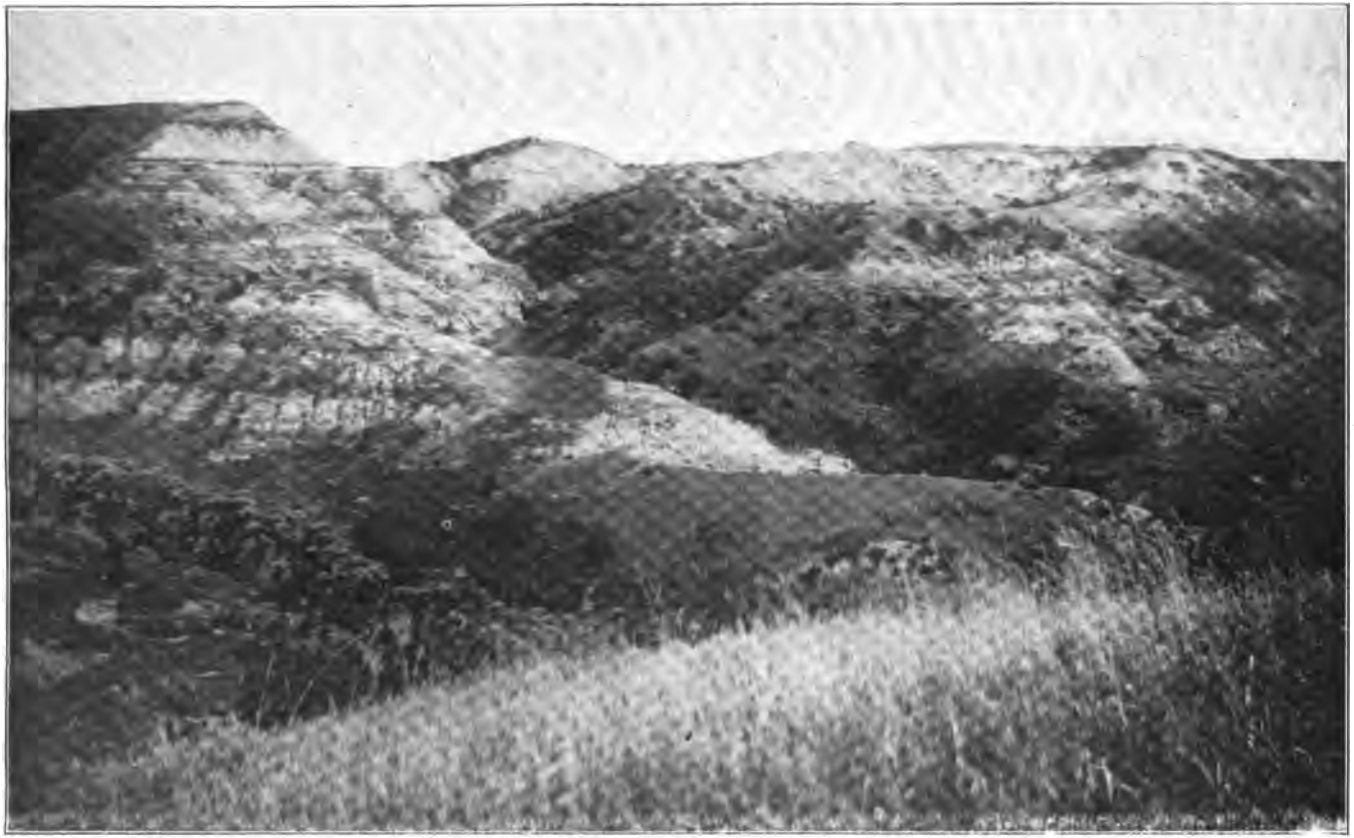
The erosion of the slopes is accomplished almost entirely by the rain that falls directly on them. A part of the rain that falls upon the flat uplands sinks into the parched surface, and the rest is prevented from running off rapidly, except at the very edge of the bluffs, where some of it gets over to increase the supply of the slopes. It will be well to consider for a moment just what happens as a result of the torrential rainfall on these slopes, simplifying the matter by eliminating for the time being the other factors, such as nature of material and vegetation.

A rainfall of one inch an hour falling upon slopes facing a ravine five rods wide at the top would be concentrated one thousand times at the bottom of the ravine. At any one point in the ravine all the water that falls above must pass, and this flow will take place about as fast as the rain falls. Where this concentration is most intense, there the steepest slopes will be found. Along the lower end of the gullies we have the effects due to the concentration on the adjacent slopes as well as that due to the run-off from points above in the gully. Here a deep, canyon-like trench is found. In walking up this trench toward the head of the gully one will find the finer materials all removed. The way in which a freshet cleans out these valleys shows that the streams at such times are far from being loaded, the competency having been greatly increased by the concentration of the flow of the waters in a short space of time. The result of this rapid flow is to undermine and to cause slumping of the looser talus material of the gulches, thus placing them in the path of the onward moving torrent, by which they are rapidly removed from the bottom of the gulch to the flatter slopes along the creeks.

At the head of the gulches the slopes through 180 degrees tend to meet nearly at a point. The effect of this arrangement of slopes is to greatly intensify the concentration of the swiftly falling waters and to greatly intensify the power of the stream for erosion. Here the slopes will often be very steep. Where two such gulches head opposite each other, the divide between is rapidly cut away, and buttes are thus isolated from the main valley wall. In many places one can travel along the tops of the thin, reduced divides, passing from one butte to another as they crown the ridge, like citadels on a castle wall. The flatness of the upland area, and the lack of seepage resulting from aridity, combine to make the direction toward which the draws head out above very indefinite. They as often head toward the river as otherwise, a fact that contributes roughness to the belt along the river by separating buttes from the main mass of the bluffs. From this manner of cutting in the draws, many buttes



Butte 500 feet high, near Squaw creek. Such buttes are seen continuously along the Little Missouri. The alluvial flat at the base of the butte is being rapidly cut away by the river



Bluffs characteristic of the Little Missouri. The slopes in the center of the field show the contrast in vegetation due to difference in intensity of sunlight

and remnants of buttes line the valleys of the creeks, in some places three orders with reference to size being found. The wider areas of bad lands seem to be due to the frequent interlacing of the heads of gullies of two or more parallel creeks.

Effect of Materials.—The effect of materials of varying hardness in the faces of the slopes is to add greatly to the roughness of the surfaces. See Plate No. XV. The sandstone concretions jut out from the clay beds and endure considerable undermining before they fall. Softer layers of clay weather away very rapidly, giving rise to shelving terraces. Coal forms a weak member of the series since it slakes readily to chips and dust, and has been burned out in many places, thus loosening great quantities of overlaying material. In a few places thin-bedded limestone adds strength to the clays, and heavy beds of a fine-grained sandstone, but slightly cemented, give added variety to the erosion forms. See Plate XVII. The materials, for the most part, however, are clays of various shades of yellow and gray, and the buttes and bad lands formed from them preserve a remarkable uniformity throughout the valley.

3. *Vegetation.*—The effect of vegetation upon topography is worthy of some attention. The region for the most part is covered with some sort of arid land plants, such as grasses, sagebrush and cactus, juniper and cedar in the ravines, and dense forests of poplar along the valleys. The slopes of the buttes and areas along the river are often entirely devoid of vegetation. This, however, is a matter of slope and exposure to sunshine and winds. The south faces of the buttes are bare and for this reason subject to active erosion, while the opposite slope is grass-covered and decidedly more gradual. Plate XVI. brings out this contrast nicely. In some areas, as one looks toward the south, nothing but long grassy slopes are seen, all of comparatively smooth surface; while the view in the opposite direction shows steep, bare faces only. In the short draws along the river, so placed that protection from winds is afforded, elm and ash were found mingled with cottonwoods. The most striking case of wind control was found at the Kildeer mountains. The mountains extend seven or eight miles from north to south, and protect the east side from the drying west and northwest winds. Here there is a heavy growth of burr oak clothing the lower eastern foot-hills in the vicinity of Oakdale. This was the only place in the whole area where an oak was found.

While it appears at present that the topography determines the position of vegetation, if the origin of the relief is considered, it can be shown that vegetation has had no small part in actually determining topographic forms. Figure 2 is a diagrammatic sketch of ravine conditions that were seen repeatedly. In one instance five parallel draws were seen which took on the characteristics shown in this figure. The ravine here represented has an east-west trend, and is about three miles long. The south facing slopes are exposed to the vertical rays of the sun during the long days of summer and so intensely heated that the growth of vegetation is impossible; consequently they are subject to intense erosion. Talus slopes and alluvial fans of rapidly shifting material accumulate in front of the slopes and push the small creek to the south side of the valley. Low buttes, remnants of the upland plain, now degraded at these points, line the base of the north slope, and increase the roughness. Small draws are heading back into the upland, cutting in behind the fluted marginal sections; these in time will stand out by themselves and be reduced to the level of the smaller foot hills seen below.

On the opposite side of the valley the slopes stand at such an angle that they never get the sunlight very directly. Plants take root and bind the soil so that strong erosion is prevented. The slopes are made more gradual, have a more regular surface, and, from the absence of gully cutting, tend to be much more permanent. The rain that falls upon the slopes gets more gradually to the creek, less material is washed from the slopes, and the creek is permanently lodged at this side of the valley. Thus it results that the valley grows in width by losing materials from the north side. The slopes in being cut back approach the divide more rapidly, and for this reason the bluffs and slopes on one side of the creek often have greater elevations than those on the corresponding opposite side. Gulches quite often occur where the banks are unprotected by vegetation, which in turn is due to exposure to wind and intense sunlight. When we consider that the protective effort of vegetation has been exerted throughout the long period during which rains and winds have been degrading these regions, we cannot doubt that plants have played a large part in modifying forms of topography.

4. *Burning Lignite as an Agent of Degradation.*—No extensive bad land areas were seen along the Little Missouri from

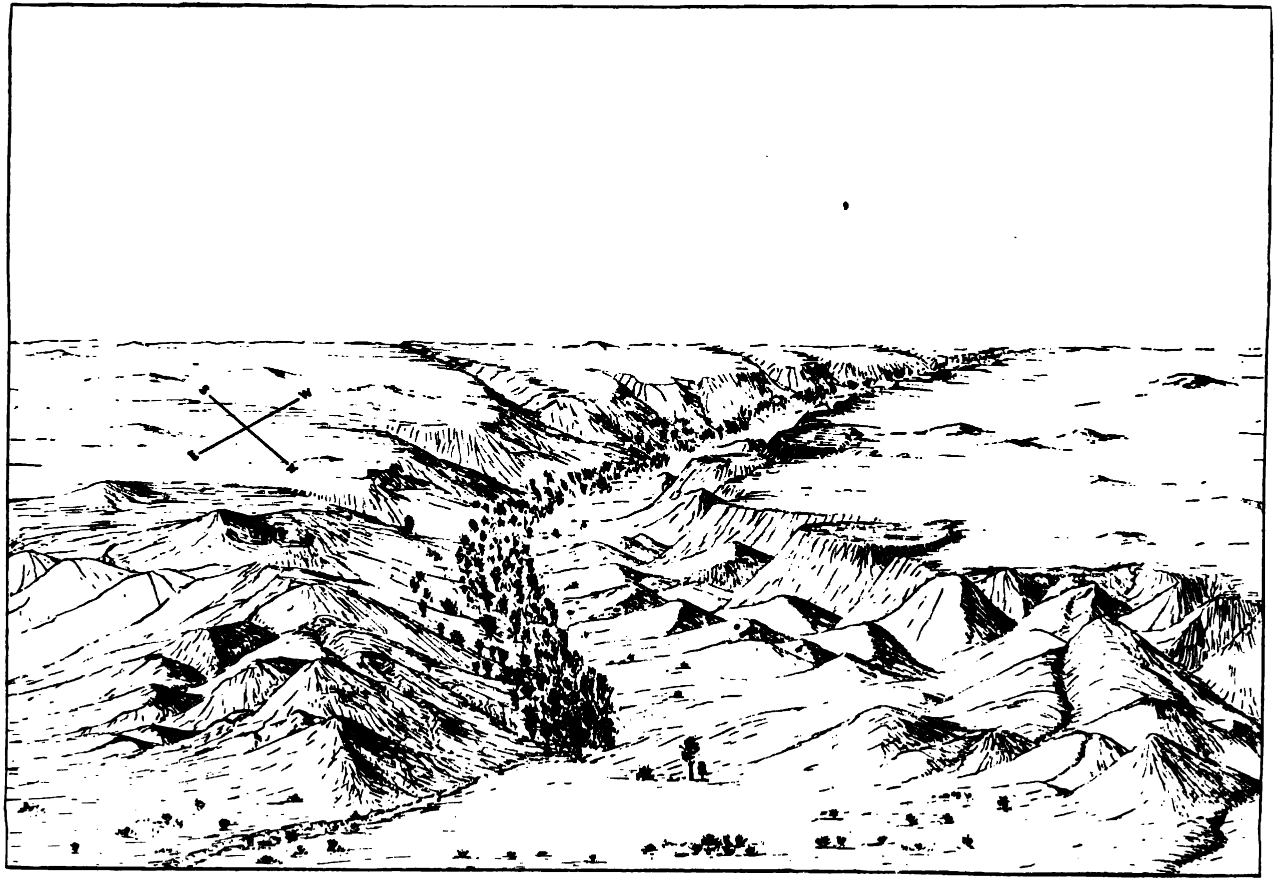


Fig. 2. Effect of vegetation on topography

which red burned clay was absent. There were tens of square miles over which the coal had entirely burned out. Perhaps the most striking area of this character is found ten miles north of Medora, as indicated on the map. But many other places were observed where heavy seams had burned out continuously along miles of the faces of the buttes. Coal was seen burning also in several places, and its effect in loosening materials noted. The burning of the coal goes on with extreme slowness, as measured in years, but rapidly compared with the erosion by rain and wind. One place was seen where the seam was reported to have been burning for twenty-two years; yet the area burned over was only about an acre. Combustion goes on, more or less smothered, under the masses of undermined clay, and since only the face of the seam is exposed the fire is greatly retarded. But even though the agent has worked slowly it has had thousands of years for its task and much has been accomplished. In fact, it seems as if most of the coal has been destroyed in this way. The way this burning aids erosion is principally by undermining large masses of clay, which when once disturbed, become easy prey for the torrential rains. In the cases observed large masses had recently slumped off from the face of the butte which extended one hundred feet above the burning seam. The lignite has the property of holding fire tenaceously, and when once started by prairie fire, or otherwise, the combustion continues until heavy slumps shut off all the air.

Not only is the material loosened, but in most cases the clays above the seam are baked hard to a depth of from ten to sixty feet; and, when gravel and sand lie near the seam, as along the Missouri below Nesson, the materials are fused to a conglomerate mass, which, by its hardness, adds to the irregularity and roughness of the surface. Large areas were seen where the surface above a burned coal seam was covered with a semi-vitreous slag, a material that has been taken for volcanic rock by some who have given the area but casual observation. Masses of this burned clay are so abundant in places that it is used largely for ballast material along the railroads, and probably this will become one of the resources of the area for railroad building, since gravel is rather scarce.

Thus in widening valleys and producing strange and excessively rough lands it seems that the burning of the lignite has had no small effect.

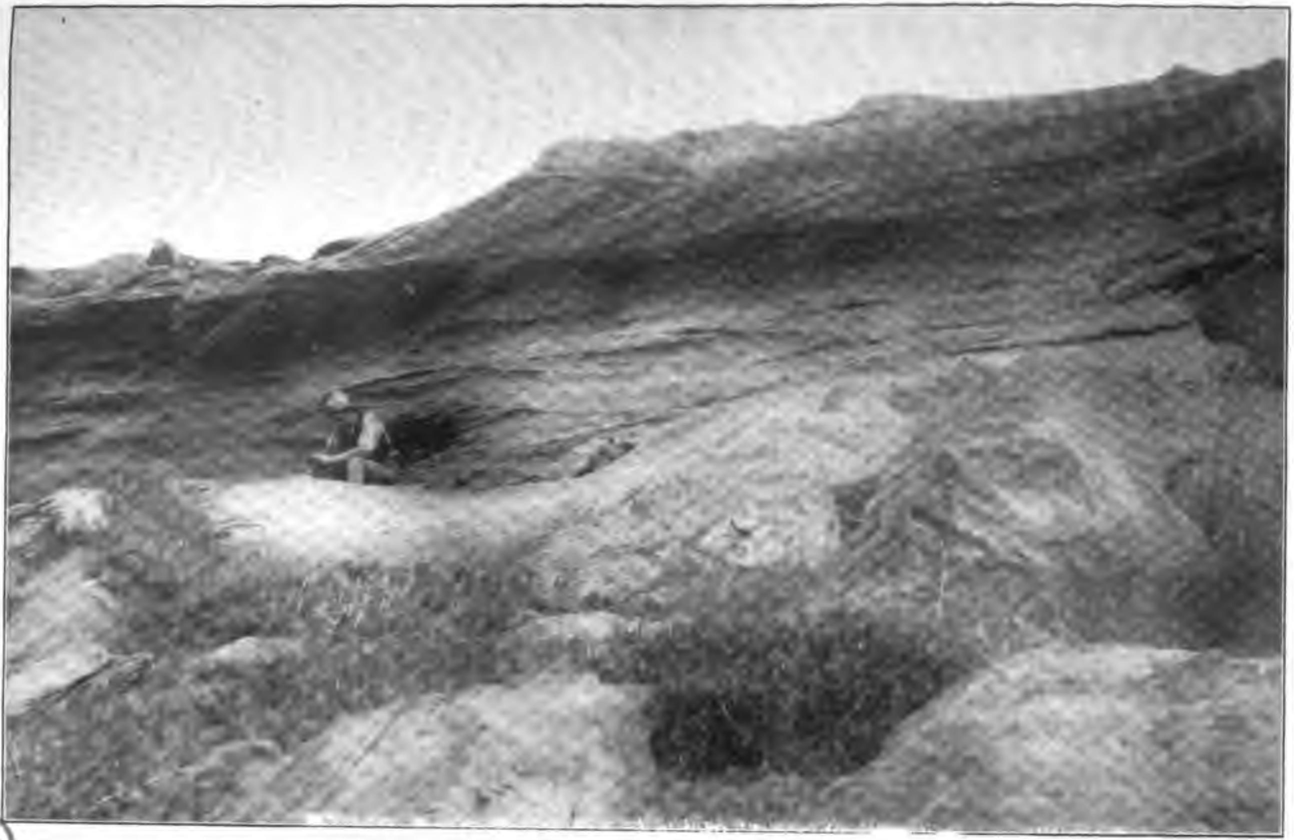
5. *Winds.*—The effect of winds in erosion in the immediate valley of the stream was not strikingly noticeable. Here the walls of the valley furnish a protection from the stronger and more continuous winds. On the uplands, however, where the winds have a clear sweep to the buttes and surfaces unprotected by vegetation, erosion is actively carried on. Small sand dunes were found near concretionary ledges of sandstone. Plate No. XVII shows the effect of rapid cutting away of crossbedded sandstone by wind work. All of the boulders of hard quartzite scattered about the plain in the vicinity of Fayette had smoothly polished surfaces. And the fact that the boulders lie out so openly on the plain may be in part due to the removal of the smaller materials by wind. The effects of winds were far more noticeable in the sandy areas about Dickinson and Gladstone than in the distinctly clay areas.

CONDITIONS THAT DETERMINE THE BAD LAND FORMS

1. *Aridity.*—The effects of aridity have already been considered as a fundamental condition in bringing about the peculiar erosion features. But there are certain other results that should be noticed which are more directly associated with the condition itself. The great excess of evaporation over rainfall has had the effect of lowering ground water level until it lies far below the upland surface. That this is the case is shown by the absence of springs from the cut banks along the river, none being found even though the conditions for springs afforded by the presence of the numerous coal seams at different levels, is very favorable. The springs seen were located far up near the head of the creek valleys, as at the X ranch, at Schafer, and at Oakdale.

As a result of the low ground-water level, the rainfall seemingly never penetrates to it; but, on the contrary, sinks only a few inches below the surface before it evaporates. For this reason seepage is prevented and little slumping goes on except where there is undermining by the stream. It is probably from this cause, together with the impenetrability of the clays, that such steep faces are maintained in the bluffs.

Again, the great dryness of the atmosphere causes the clays to crack up greatly, so that, for a depth of a few inches below the surface they are in condition to absorb water like a sponge, greatly facilitating the dissolution of the faces as well as the more shelving ledges of the buttes. The coal seems also dry out



Cross-bedded sandstone, showing wind erosion. Northwest of Dickinson

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and crumble to powder, furnishing weak layers that hasten underming. Further, the aridity keeps the sandy clays in a dry state, and ready to be swept away by the winds, or loosened up so that they are easily transported by the torrential rains.

2. *Uniformity of Materials.*—The fact that the strata consist almost entirely of materials of uniform texture, in a broad way, furnishes the basis for great uniformity of topography. Bad lands and bluffs seen at one part are not unlike those seen at any other in respect to general outlines. The same strata of clays are continuous for miles along the river, and striking seams of yellow clays were observed to be continuous in the valleys of both the Little Missouri and the Missouri river, while the bluffs formed in these beds were remarkably similar. Aside from all these minor differences in form, that disappear with distance, the bad lands at one place seem exactly like those of another, and getting lost in the bad lands is as easy as getting lost in the woods.

The great fineness of most of the materials prevents the penetration of rainfall and compels flow over the surface. Further, small depth of penetration of water at the surface of the pes prevents any great effects from freezing and thawing. ants also do not readily get a foothold in such surfaces. The effect is to decrease the rate of erosion.

3. *Horizontality of Bedding.*—The fact that the beds are horizontal removes the tendency to weakness along bedding planes. Slips that would be common with tilted strata seem for the most part largely absent here. The presence of these horizontal beds over wide areas tends to make valley erosion uniform with respect to slope. The effect of the plants in maintaining slopes and thus producing regularity has been mentioned above.

4. *Concretionary Forms.*—Irregular concretionary forms are very common in many parts of the bad lands. These occur in a great variety of shapes from those of great cylindrical masses of sandstone to small toadstool like forms found occupying the shelves of the buttes in great numbers. Together with the petrified stumps and seams of sandstone, all these masses of greater hardness than the surrounding clays, add much variety to the roughness of bad land forms. These concretions probably, on the whole, tend to retard erosion. The fact that they remain in many places long after the clays about them have been carried away, seems to indicate that they act to check the

work of water on the faces of the buttes about them, though they do break up the continuity of the horizontal bedding.

TOPOGRAPHY OF THE DRIFT AREA

Boundaries.—The area included within the margin of the drift lies largely east of a line running from northwest to southeast through the Kildeer mountains. It coincides practically with the basin of Knife river and its tributaries, and is continuous with the similar topography north of the Missouri and west of the coteau of the prairies. On the east of the Missouri the flatter uplands, rising 300 to 400 feet above river level, merge with the hill belt. On the west side, in the longitude of the Kildeers, the transition to the upland flats, east of the Little Missouri, is gradually passing through a marginal zone where bad land types and drift covered surfaces blend. In some places the western limit of drift is sharp, but in many others extremely indefinite.

Valleys and Slopes.—Throughout this entire area the valleys seem to be entirely too large to be the work of streams now flowing through them. The lower fifteen miles of the Knife river valley is from two to three miles wide, and this unusual width is maintained far up both Knife river and Spring creek. The area of the valleys as compared with the uplands at the heads of the creeks is also very large. Here the valleys really give way to broad depressions between the low hills. Spring creek, Hans creek, Deep creek, and others, now flow in narrow channels across the flat floor of rather broad valleys.

The slopes from the divides to the stream levels are, as a rule, gradual. This fact tends to greatly increase the apparent width of the valleys, since in some places it is difficult to tell just where the valley ceases and the upland begins. Sharp slopes have been toned down by the passage of the ice. The irregular manner in which these slopes have been planed down gives the valley a decidedly unsymmetrical appearance. Buttes and short series of bad lands that hem in the stream at one point give way to long, gentle slopes at another, which extend gradually down from the divides until they meet near the stream levels. For this reason the valley seems wide at one point and very narrow at another. The older preglacial valleys of these streams were probably as uniform in shape and cross section as that of the present Little Missouri. Plate XIX, together with the cross sections of these stream valleys (Figure 1), will furnish a better idea of the slope than it is possible to give in words.

Distribution of Rough Lands.—If flat upland once existed here, little of the former surface now remains. A view from any of the higher hills of the valley shows lower hills of greater variety, both in elevation and manner of placement, with rather wide valley spaces intervening. Most of the hills are rounded and have long, gradual slopes that blend with the slopes leading down to the stream. In outline the hills also present great variety. Some are round and conical with broad flat areas between them. Others are long and ridge-like, and represent the greatly modified and reduced preglacial divides. There are all grades and sizes from that of the low mound to the rough bad land brakes that crown the crest of the divides between Knife river and Spring creek. Around the Kildeer mountains there is a series of low, knob-like foot hills, which represent the old buttes at the heads of the ancient creeks.

The Kildeer mountains have been preserved by a heavy cap of of dolomitic limestone from degradation by water, and by their altitude from the effects of the ice. They stand 500 feet above the lower hills about them.

Small, island-like patches of rough bad lands, somewhat reduced in elevation, extend between Fayette and Taylor. These areas, while not covered, are surrounded by drift materials, boulders and gravel, which shows that they were too high to be much affected by the ice or the water flowing from it. In some places steep, unmodified bluffs are found along the streams.

Minor Features of Topography.—Terraces twenty-five to sixty feet high were seen bordering the Knife river below Fayette. In the valley of Deep creek south of Rockspring gravel covered terraces twenty and forty feet high were found. Along the Knife valley below Broncho, three distinct terraces were observed at elevations of twenty, forty and sixty feet above the river. Old terrace levels of a height of thirty to fifty feet, capped with coarse gravels, were seen along the lower part of the Little Missouri valley. Streams have cut their channels down from thirty to sixty feet since these terraces were formed.

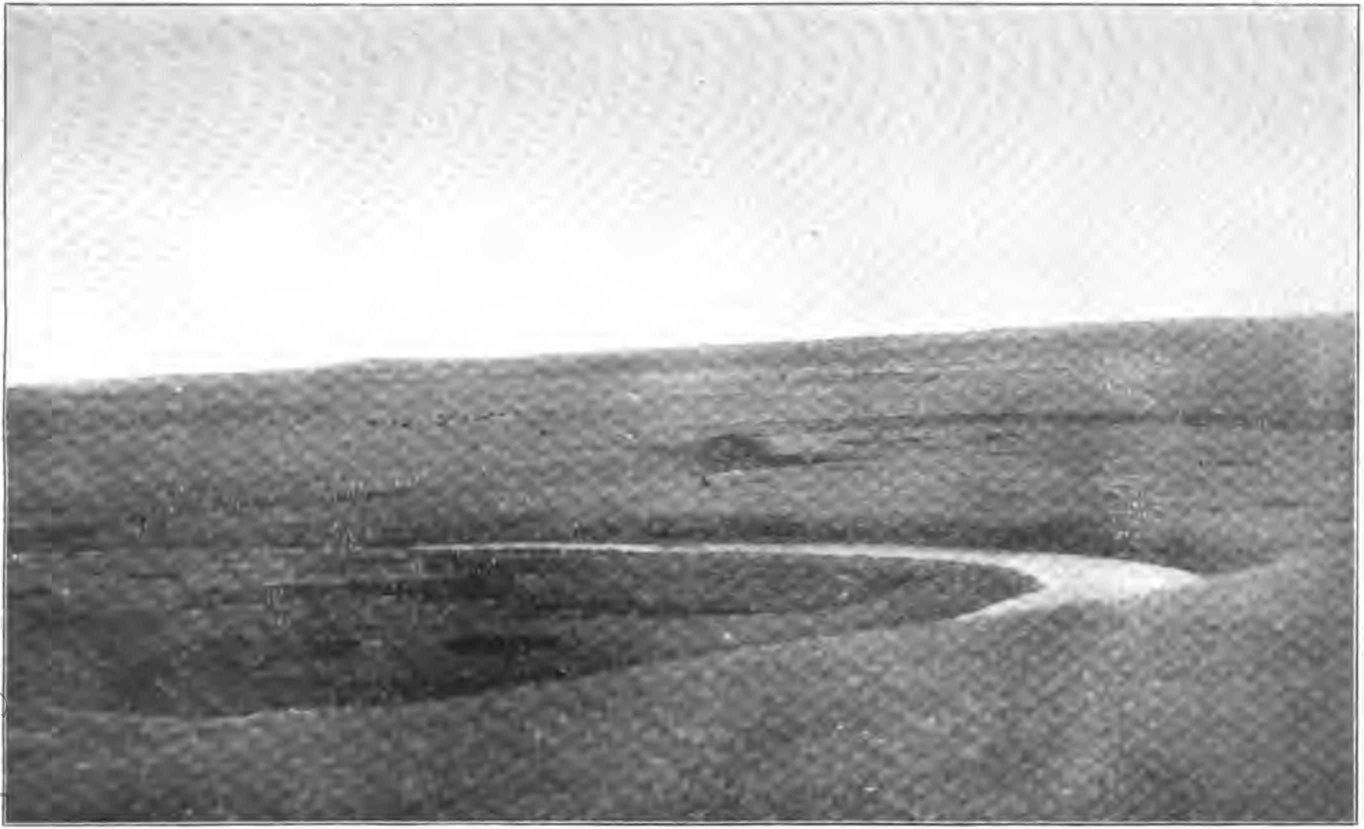
Sloughs.—Sloughs are not common in the area. Some are found south of Rockspring and along the divide north of Spring creek. Large hay sloughs are reported to exist on the divide between the Knife and Spring creek. There are extensive areas east of the Kildeer mountains and along the Knife river above Fayette that have the appearance of old lake beds. In fact a small lake is found, at the present time, northeast of Oakdale.

Drift Forms.—The drift was prevailingly thin, and few places were found where the topography was entirely determined by it. North of Halliday, along Hans creek and further east, low, rounded hills covered with several feet of glacial materials were seen. Several knobs of till, consisting of clay, coarse and fine gravel, and boulders, occur along the south bluff of Knife river. This material has the appearance of having been wedged into the old valleys as the ice advanced up the south slope of the river. Boulder trains are numerous, and their presence is usually marked by a slight rise in elevation, as if they had protected the surrounding clays from degradation.

On either side of the Little Missouri near its mouth, many low, rounded hills capped with a coarse, flinty gravel take the place of the steep-faced buttes. They seem to have been in such a position with reference to the ice that they were greatly modified by the outflowing waters which carried the gravels that are now found on the hills.

Dunes.—A large group of dune hills from twenty to sixty feet in height are found on the east side of the Knife river extending for ten miles above Stanton. These forms cover many square miles, as shown on the map, and probably represent wind work on wide flats formed some time during an obstruction of the Missouri below this point. The elevation of the hills is from eighty to one hundred and fifty feet above the level of Knife river.

Origin of the Topographic Forms.—These forms of relief, so strikingly different from those of the Little Missouri, owe their present outlines to the action of water and ice. The great reduction in elevation is due to both water and ice, as will be explained later. The area was at one time of much simpler configuration, a mixture of rough bad lands with wide stretches of flat upland plain, similar to the region west of it along the Little Missouri. The ice sheet, several hundred feet thick, passed over this more simple preglacial erosion topography, and the long series of consequences due to obstructing creeks, turning rivers out of their courses, deposition of boulders and other drift materials, combined with the flow of water from the melting ice, left the surface in the confused state of relief in which we find it today.



View of Spring Creek valley, near Paulson's ranch

CLIMATE

For the purposes of that part of this report bearing on irrigation, it is necessary that certain elements of climate should be considered. In the report that follows, the data have been taken from the report of the United States Weather Bureau, from the reports of the North Dakota Experiment Station at Fargo, and from the statements of individuals who have spent some time within the area. Since this discussion of climate is made with reference to the agricultural possibilities of the region, some tables are introduced bearing on the question of crops. The tables of temperature are compiled from the reports of three cities on the border of the area, Miles City, Bismarck and Williston, since no observations are available from the central part of the area.

The aridity of this region, in common with that of all the great plains, is due to the presence of the Rocky Mountain barrier, which intercepts the moisture of the prevailing westerly winds. The variability of the conditions of the weather depends upon the cyclonic storms that pass over the United States in a more or less regular succession the year round. The most striking characteristic of the weather is the extreme temperature range of the year, the record showing, at Medora, a maximum of 114 degrees F. and a minimum of -40 degrees F., or a range of 154 degrees. This approaches the range of temperature for eastern Siberia, 171 degrees, which is the highest of the earth.

Winds.—Next to latitude, the position of an area with reference to prevailing winds is the most important factor in the control of the climate, because winds determine the rainfall. The prevailing direction of the wind for the fall and winter months is northwest, while for the summer it is variable. The directions most likely to be followed by rain are southwest, south and northeast. The area is to some extent affected by the chinook winds from across Montana. These, being warm and dry and continuing for some hours, dry up the snow from the plains, making it possible for cattle to feed out for a large part of the winter.

Temperature.—The region is characterized by high summer temperatures and cold winters with extremely low temperatures during the passage of areas of high pressure. At such times the cold air of the "high," coming from upper altitudes of the atmosphere, settles over the region and drives the mercury in the bulb down almost to its freezing point. Such extremely low temperatures are only occasional. At Williston, the low reading of –41 degrees was recorded once on 1889; at Miles City, –49 degrees was the record corresponding to that of Williston. At Williston the record shows that a temperature of –20 degrees occurred fifteen times during the three years 1896-9.

The following table shows the extreme maximum and minimum temperatures at Williston, Miles City and Bismarck for 1897:

Month	Williston		Miles City		Bismarck	
	Max.	Min.	Max.	Min.	Max.	Min.
January	38	-32	54	-28	42	-30
February	32	-25	43	-20	33	-25
March	47	-35	53	-26	48	-36
April	90	20	88	28	81	19
May	90	25	92	36	90	28
June	101	32	101	42	95	33
July	98	46	100	45	99	47
August	97	40	100	47	93	43
September	94	30	98	30	102	32
October	93	17	88	22	89	13
November	69	-19	76	-26	72	-15
December	49	-26	51	-31	52	-23
Year	101	-35	101	-31	102	-36

With reference to these extremely low temperatures it may be said here that the severity of the cold is greatly mitigated by the prevailing dryness of the air. This point will be considered more at length under the head of relative humidity.

Normal Monthly Temperatures.—While it is important to know what the extremes of temperatures may be, it is perhaps more important, to stock men at least, to know the normal or average temperatures that prevail during the winter months, especially; while to the farmer, the temperatures of the growing season are most important. The following table shows the normal temperatures for Bismarck, Williston and Miles City:

Place	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Bismarck—av. of 21 yrs	4.5	9.5	22.6	42.1	54.2	63.8	69.5	67.5	57.0	43.8	25.9	14.7	39.6
Williston—av. of 17 yrs	3.9	7.7	23.5	42.6	53.2	63.3	68.5	66.5	55.5	43.2	26.1	13.0	38.9
Miles City—for 1897....	14.9	15.2	15.4	47.6	63.5	67.0	72.5	71.7	66.6	49.0	25.2	18.8	44.0

A comparison of the figures of this table with similar data from other places of the north central part of the United States and Canada shows that the winter temperatures of the region are similar to those of St. Paul, north central Minnesota and northern Ontario. For July the comparison shows that the region lies in the same belt as southern Minnesota, central Wisconsin, central Michigan, southern Ontario and New York.

So far as the summers are concerned, the region has a more agreeable temperature than the more humid areas with which it is compared. The figures given for the normal temperature of the summer months should be accompanied by figures to show the daily range and night temperatures for the same period, since the comparatively low normals are due to the relatively cool nights. While the heat of the midday sun in the bad lands is excessive, continuing for weeks together to rise to 90 or 100 degrees, the radiations of the nighttime offset the higher temperatures of the day. The following table shows the mean and extreme daily ranges of temperature for the stations, Bismarck, Miles City and Williston:

Month	Bismarck		Miles City		Williston	
	Mean	Extreme	Mean	Extreme	Mean	Extreme
January	22.5	71	21.1	76	15.6	67
February	23.2	77	22.2	70	23.7	70
March	20.7	83	20.6	89	20.3	71
April	20.9	61	24.3	60	21.7	66
May	23.8	58	24.2	46	20.6	42
June	21.6	54	29.3	57	24.4	52
July	25.6	60	27.2	54	23.9	54
August	28.8	58	30.4	56	27.6	56
September	27.4	71	26.5	62	21.9	64
October	24.6	64	24.3	70	28.0	72
November	29.6	70	14.2	96	14.9	62
December	18.5	69	17.8	66	20.3	74
Year	23.0	126	23.8	123	22.2	122

From the above table it will be seen that while the mean daily ranges of temperature, as shown by monthly averages, are rather high, the extreme ranges are remarkably high for both winter and summer. A night temperature of 45 degrees is not uncommon along the valleys of the streams during midsummer. The following table shows the afternoon and early morning reading at several places that have similar normal temperatures for summer.

Month	Bismarck, N. D.			St. Paul, Minn.			Detroit Mich.		
	4 p.m.	7 a.m.	Difference	4 p.m.	7 a.m.	Difference	4 p.m.	7 a.m.	Difference
January.........	15.8	5.7	10.1	15.6	6.8	8.8	33.6	26.4	7.2
February	14.6	2.0	12.6	19.2	9.2	10.0	38.0	30.3	7.7
March	32.0	16.9	15.1	33.4	22.2	11.2	47.1	36.5	10.6
April............	50.0	34.1	15.9	52.5	39.4	13.1	60.7	48.5	12.2
May.............	61.5	43.0	18.5	62.6	49.0	13.6	68.3	55.7	12.6
June	71.4	54.7	16.7	74.6	61.0	13.6	81.1	68.2	12.9
July...	79.6	58.6	21.0	79.8	62.4	17.4	83.0	68.7	14.3
August..........	80.7	56.1	24.6	78.1	60.3	17.8	82.8	67.6	15.2
September......	71.9	48.4	23.5	72.3	55.2	17.1	78.6	62.5	16.1
October....... .	55.6	35.3	20.3	55.3	41.7	13.6	63.4	47.6	15.8
November	31.5	20.3	11.2	34.0	24.7	9.3	47.0	37.7	9.3
December	22.4	11.7	10.7	25.0	18.3	6.7	41.6	33.5	8.1
Year	48.9	32.2	16.7	50.2	37.5	12.7	60.0	48.6	11.4

A comparison of the columns of difference in the above table shows that average fall in the night temperatures during the summer months at St. Paul is from 70 per cent to 80 per cent, and at Detroit 50 per cent to 70 per cent of that which occurs at Bismarck. These figures, as will be shown later, are significant with reference to the growth of certain crops.

Killing Frosts and Length of Growing Season. — It is important to know the length of the season for growing crops, as determined by the earliest and latest killing frosts. Here the farmer should know not alone the average time of first and last frosts, but the average extreme earliest and latest frost, since it is the time within these limits that he must feel reasonably sure of.

The following table is compiled from observations made by the Weather Bureau at Bismarck, Miles City, Williston and Medora during the years 1896-1901:

Year	Bismarck, N. D.		Medora, N. D.		Miles City, Mont.		Williston, N. D.	
	Latest Frost in Spring	Earliest Frost in Fall	Latest Frost in Spring	Earliest Frost in Fall	Latest Frost in Spring	Earliest Frost in Fall	Latest Frost in Spring	Earliest Frost in Fall
1896-7	May 1	Sept. 10	June 7	Sept. 8	May 15	Sept. 17	April 24	Sept. 10
1897-8	June 7	Sept. 16	June 7	Sept. 18	May 14	Sept. 16	May 14	Oct. 8
1898-9	May 4	Sept. 9	May 3	Sept. 3	May 4	Sept. 10	May 6	Sept. 9
1899-1900	May 13	Sept. 19	June 6	....	May 4	Sept. 28	May 17	Sept. 29
1900-1901	April 18	Sept. 26	May 16	Sept. 17	April 17	Sept. 25	May 6	Sept. 27

The temperature of 26 degrees F. is taken as that for a killing frost.*

From the above table it will be seen that the range between the earliest and latest killing frosts is from April 18th to October 8th. The minimum range is from June 7th to September 3d. Mr. Ladd, of the Agricultural College at Fargo, finds at the experiment station from a record of seven years, that the average latest spring frost is on May 23d, and the average of the earliest fall frosts September 12th. This gives the growing season an average length of 111 days. Given such a length of season of growth, one may be sure of the successful raising of most farm crops. The following table taken from bulletin 52, already referred to, shows the number of days necessary to mature some of the more important crops:

CROP	PERIOD
Wheat	83 to 123 days
Oats	88 to 116 "
Barley	82 to 94 "
Millet	81 to 112 "
Spelt	91 to 92 "
Corn	about 100 "

Wheat should be sown not later than the 29th of May, and oats not later than June 4th.

Rainfall.—The rainfall of this area, in common with that of the rest of the state and of Montana, comes largely in the summer during the growing season, and in connection with migratory areas of low pressure that pass across the United States.

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*Bulletin 52, North Dakota Agricultural Experiment Station.

The following tables of rainfall and snow are adapted from the report of the Weather Bureau for 1896, and from the Smithsonian Report on Precipitation in Rain and Snow in the United States, by Charles A. Shott:

Stations	Years of Record	Rainfall and Snow at Places in Western North Dakota															
		Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean	Highest	Lowest	Total May to Sept.
Bismarck	22	0.6	0.6	1.1	2.3	2.5	3.5	2.3	2.0	1.2	1.0	0.8	0.6	18.5	31.0	11.2	10.3
Ft. Buford	29	0.6	0.5	0.6	1.2	2.4	2.8	1.7	1.2	0.8	0.8	0.6	0.6	13.8	23.3	7.3	8.1
Ft. Stevenson- 1867-1874	6	0.52	0.28	1.06	0.85	1.5	1.87	1.2	1.9	0.89	0.83	0.43	0.51	11.48	....	....	6.47
Ft. Totten,—1869-1874	5½	0.82	0.47	1.33	1.32	2.53	3.07	1.68	2.76	1.14	0.48	0.88	0.30	16.78	....	....	10.04
Ft. Totten	21	....	....	....	1.4	2.3	3.7	2.4	2.5	1.	....	....	....	Total 13.3	....	....	10.09

COMPARATIVE TABLE

RAINFALL OF GROWING SEASON IN HUMID REGIONS

Place	Rainfall	
	May to September	Annual
Lansing, Mich.—32	14.2	31.6
Madison, Wis.—27 years	15.1	33.2
Minneapolis, Minn.—37 years	14.7	28.2
Chicago, Ill.—29 years	13.7	34.0
Indianapolis, Ind.—26 years	16.0	42.0

The above table shows that, though much of the rainfall occurs during the four months of the growing season, the quantity will be insufficient for most years. Occasional years will increase this amount by a third or a half, when the quantity will compare favorably with the average rainfall of humid regions for the same period of time. It appears, therefore, that the only way for the farmer to be sure of his crops is to resort to irrigation to supplement the uncertain and irregular rainfall.

It must not be thought, moreover, that the quantity of rainfall in winter is without its significance for the farmer. The fact that but small quantities of rain and snow fall in the winter months is one reason why the region is so dry in summer. For, since too little moisture is furnished to saturate the ground, the ground water level remains permanently far below the surface, and is but slightly affected by the occasional rains. The relatively dry atmosphere, then, quickly catches up the water that falls upon the surface as rain or snow, and, for lack of resource in the ground water, remains permanently far below the saturation point, and hence capable of rapidly evaporating the large quantity that falls in the growing season. The demands of evaporation then are always in excess of supply, and hence a permanently arid condition is produced. There is another feature of the rainfall that must not be overlooked. The large part of the summer supply comes in torrential showers, which from their very nature, furnish but an irregular and patchy distribution of rain. Some parts of the Little Missouri valley may, it is believed, pass whole seasons with but a third or a quarter of the average amount stated in the above tables.

The favorable feature of the small winter precipitation and low relative humidity appears from the fact that the snow usually comes in small quantities and remains so dry that cattle can feed for a large part of the winter.

In the fact of summer rains the influence of five important factors is seen. These are the following: 1. The cyclonic storm; 2. The migration of the belt of cyclonic storms in latitude; 3. The change of temperature in the area north of the Gulf of Mexico; 4. The Gulf of Mexico; 5. The presence of the Rocky Mountain barrier. It is unnecessary to state the laws of the storms that pass continuously across the North American continent; but the effect of the passage of an area of low pressure is to cause the air to move toward the center of the area from all sides. The directions along which the movement is most marked are, in this part of the United States, southwest, south, southeast, northeast and northwest. The currents from the south come from a region of higher and those from the north from a region of lower temperature than that of the storm center. The mingling of these masses of air of different temperature and humidity leads to precipitation over some part of the area of low pressure. Rain may fall either in steady showers or in thunder storms, often accompanied by hail, the nature of the shower depending upon the season and local conditions. During the passage of one of these areas of low pressure the winds shift in direction due to a change in the relative position of the storm center and the place of observation. The succession of winds is south, southeast, east, northeast, north and northwest if the observer is north of the path of the center of the "low," and south, southwest, west and northwest if the station is south of the center of the "low."

The "low" is followed by a "high" pressure area, which has characteristics quite the opposite to those of the "low." The "high" is marked by winds moving outward from the center of high pressure, clearing, rainless sky, lower relative humidity and a marked decrease in temperature. The "high" is often accompanied by a cold wave, that in this region drives the mercury down from 25 degrees to 40 degrees in the winter.

These storms pass in succession every three or four days, so that the area is under the influence of either a "low" or a "high" almost continuously, and to these conditions the rainfall, as well as frequent changes in temperature, is due.

The belt affected by these storms shifts its position from the central and southern part of the United States to the northern part during the spring and summer.

The effect of this oscillation of the belt of storms, combined with the rise of temperature from winter to summer, is to carry the belt of rainfall progressively farther north during the spring and summer, so that in Texas much of the rain falls in the spring, in Kansas in the late spring and in the Dakotas and Montana in May, June and July. This follows as a natural consequence from the law that precipitation does not take place until the air is cooled below the dew point, and obviously such a cooling would occur much further to the north in summer than in winter.

The Rocky Mountains on the west and southwest of this area form a barrier that intercepts and condenses on its western slopes a large part of the moisture of the air that has succeeded in passing the coast ranges still further west. For this reason the region is semiarid. Thus limited on the west the supply of moisture must come largely from the Gulf of Mexico.

While the rainfall comes mostly in the summer season, due to the conditions stated, the minor amount of precipitation during the rest of the year also comes, in part though less directly, from the gulf, and in part from the evaporation and precipitation of the waters from the adjacent land areas. There is much of this drifting of the moisture of the air, and it has been shown that the rain which falls in Montana, for example, may have been reevaporated and reprecipitated several times on its way from the gulf to the interior.

Snow.—The common practice of winter grazing over much of this area indicates that the snowfall is generally light. In favorable years stock feeds out on the plains all winter. The amount of snowfall varies from a few inches to two feet. It usually covers the ground for four or five months, or from sixty-five to 160 days and little falls before the first of January. Some snow may fall by the first of October, but this usually passes away quickly and a mild period, called "Indian summer" occurs between October and January. Mr. Pease stated the following as examples of winter condition which he observed during a seven years' residence in the area. "In the winter of 1898-99 there was no snow after the October fall, which soon disappeared, until the second week of January; the weather was mild during this time. In 1899-1900 the spring thaw occurred the first week in March, so that plowing was done and seeding over before the first of April. In 1902-03 there was little snow in the vicinity of Dickinson before the first of March. In 1899 a three days' blizzard occurred the 4th of May, bringing much snow and causing a great loss of stock. The temperature during this storm was not lower than 22 degrees F."

A comparison with the snowfall of the other parts of the United States shows that the Missouri valley has less snow than areas either east or west of it. In northern Michigan, the snowfall is 130 inches; in St. Louis, twenty inches; in Utah and Montana fifty inches; while the average in the Missouri valley is about thirty inches.

The number of days with precipitation, both rain and snow, is about 100. The greatest number of consecutive days with precipitation is from ten to twenty; the greatest number without precipitation varies from thirty to sixty.

Sunshine and Relative Humidity.—Not the least among the elements of climate are those that add to the pleasure of living within an area. Some of the earliest and highest civilizations grew up within regions characterized by a high percentage of sunshine and low relative humidity, accompanied by aridity and rather high temperatures. Especially is it true that the more arid parts of North America were inhabited long before the appearance of the European, by tribes of Indians whose strength of body and vigor of intellect were surpassed nowhere else in prehistoric America.

Just what the beneficial influence of sunshine on the health of man may be it is difficult to state; but it is generally recognized that those lands with a high per cent of clear, sunny days conduce in some way to a more vigorous expression of the vital forces. It is certain that the combination of the sunshine with low relative humidity has the physiological effect of enlivening and stimulating to activity. According to Pettenkofer and Voit,* an adult man eliminates about 900 grams of water from his skin and lungs daily. Of this amount 450 grams come from his skin alone. A change of even one per cent in the relative humidity of the air causes very perceptible changes in the amount of evaporation from the skin. If the evaporation from the skin is diminished, the amount of urine is increased, and also in many cases the secretions of the intestines, both of which may lead to injurious effects upon the body. Further, the less diluted blood of dry climates acts as a stimulant upon the nervous system, increasing its functions. If not carried to extremes, it will be seen that this latter effect of increasing the nervous activity would be conducive to the higher mental activity, and hence increased culture. It is when dry climates and extremely moist climates are compared that the beneficial effects are most noticeable. Damp air and increased pressure have the following physiological effect: Nervous depression; quiet sleep; increased elimination of carbon dioxide; slower circulation of the blood. Dry air and decreased pressure have these effects: Nervous excitement; sleeplessness; quickened pulse; a drier skin and decreased temperature.

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*Hann. Handbook of Climatology.

Here it may be stated that the ordinary changes of the atmospheric pressure, equivalent at most to a change of altitude of a few hundred feet, have very little if any physiological effect. The effect is due then, in the cases mentioned above, to the change in the moisture in the air. When the moisture content of the atmosphere is large, the effect of changes of temperature is much more noticeable than when the air is dry. For this reason the inhabitants of deserts and dry climates endure, without discomfort, great changes in temperature which would be intolerable in moist climates. Von Middendorff* in describing the climate of eastern Siberia, says; "It would be impossible for man, with his nomadic habits of life there, to endure the extreme cold of western Siberia unless he were helped by the dryness of the air. Fur clothing which has become damp during the day through evaporation from the body, is laid inside out on the snow during the night and in the morning it is completely dry."

While we do not forget that to the dryness of the atmosphere of this area can be attributed the absence of forests and vegetative productivity which is the source of wealth in more humid climates, yet to the few who live here the extremes of both winter and summer, as well as the greater variability of temperature, are made much more tolerable.

Records show that from forty to sixty per cent of the midwinter and from sixty-five to seventy per cent of the midsummer days are clear. The degree of sunshine increases toward the last of the summer. It may also be said that the density of the cloud bank on cloudy days cannot be as great as that of more humid areas. The clouds will therefore have less effect upon the radiations from the surface of the earth.

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*Quoted by Hann from Thomas: Beitrage zur Allgem. Klimatologie.

The relative humidity, upon which cloudiness depends, is on the average seventy per cent. This is the same as that of Chicago during the dryest days, or when the winds are from the west or southwest.

The following table presents a comparison of the relative humidity of several different areas:

TABLE OF RELATIVE HUMIDITY

Place	January —per cent	February —per cent	March —per cent	April —per cent	May —per cent	June —per cent	July —per cent	August —per cent	September —per cent	October —per cent	November —per cent	December —per cent	Year —per cent	No. of Years Observation
Bismarck	78.9	79.0	76.1	70.2	66.7	70.7	66.6	63.3	65.4	71.2	77.8	77.4	71.9	9
Williston	79.6	80.8	75.0	61.2	58.2	63.1	57.7	54.2	57.9	64.1	75.4	76.9	67.1	9
Miles City, Mont	82.0	80.6	75.4	62.4	57.6	57.4	48.2	44.0	53.8	64.2	76.3	78.3	65.0	5
Des Moines, Iowa	77.4	75.4	70.1	64.4	65.8	69.9	66.7	69.0	70.6	67.1	71.2	76.0	70.3	9
Kansas City, Mo	75.8	75.5	71.1	62.0	69.5	71.1	70.8	71.4	71.9	65.7	70.2	74.4	71.3	8
Pueblo, Col	55.5	49.9	43.8	37.6	43.5	3929	47.6	49.4	41.9	43.9	50.0	53.6	46.2	9
Salt Lake City, Utah	73.3	70.7	60.8	49.3	47.3	39.9	37.0	37.4	41.2	52.1	63.0	72.1	53.7	9
Yuma, Arizona	45.4	43.8	43.9	35.1	36.7	34.7	42.8	47.4	44.7	46.2	43.3	51.4	42.9	9

The figures of this table show that this region of North Dakota can scarcely be classed with the extremely arid regions of the southwestern and western United States. Rather, it is intermediate between the humid east, and the dry west, and the term sub-humid properly applies to it.

VEGETATION IN THE REGION

Any extended discussion of agriculture and crops is entirely outside the province of this report; as a supplement to what has already been said of climate and irrigation, however, attention will be called briefly to the geographic factors in the distribution of some of the more important agricultural resources.

Some interesting facts concerning North Dakota have been brought out by Mr. Mark Alfred Carlton in a study which he has made of the climate and agricultural products of Russia.*

Mr. Carlton states that many of our most valued varieties of grain came originally from some part of Russia. The red winter wheat called Turkey wheat, which has been grown in the great plains for twenty-five years, came from Crimea. Probably, also, the entire group of Fife wheats came from Russia, for they are similar to the Ghirkas of the Volga region. Furthermore, a series of field experiments with 1,000 varieties of wheat, and 300 of oats, barley, rye and spelt, have been carried on by the agricultural department for four years, and it is found that Russian cereals, especially the wheats, are best adapted to culture on the prairie and northern parts of the United States.

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*Bulletin No. 23, U. S. Department of Agricultue.

The investigations with respect to soils and climate show a striking parallelism between certain parts of central Russia and western North Dakota. First in respect to soils; there is the same gradation between black, humus prairie soil, through acid, neutral and alkaline soils that appears in the prairie of the west; there is also a similar combination in the soil of salts which are useful for plant growth. It is quite likely, although no test has been made, that the soils of the river valleys have chemical and physical characteristics that would make them compare favorably with the "black earth" region of Russia.

The climatic parallel is even more striking. In the greater portion of the two regions the winters are long and severe, while the summers, though short, are intensely hot. Other noteworthy features of the climate are, (1) the great number of clear days in the year, (2) the extreme amount of precipitation during two or three months of summer as compared with that of the remainder of the year, (3) the character of this precipitation, falling in quick thunderstorms, as a rule, with very few days of mist or fog, (4) the excessive heat of midsummer, following intensely cold winters, as already mentioned, and (5) the comparatively light snowfall." These characteristics of climate seem to be more pronounced in Russia than in the area under consideration. It is for this reason that Russian crops seem even better adapted to these northern, semiarid parts of the United States, than to their native habitat.

At Samara, near the heart of the Volga country, the rainfall is 15.6 inches, which, it will be seen is about the same as that of the Little Missouri basin. The normal temperature of Samara, 39.3 degrees F., is slightly less than that of Bismarck, while the July normal is 1.1 degrees higher than at the same place.

Botanical investigations have shown that plants subject to the above mentioned characteristics of climate are constituted differently than plants of the humid region. Such plants have adaptations that enable them to resist, to a certain extent, the evaporating power of hot, dry climates. The cereals grown for centuries in Russia very naturally thrive here. As an example of what is possible in this state, certain examples of the growth of grain in Russia may be stated. The Perm and Vyatka areas having a climate as dry as that of western North Dakota, have stood two years at the head of Russia districts in growing oats. Samara stands forth as a spring wheat district.

Several of these varieties of wheat, oats and rye are well adapted to the valley lands of North Dakota. In their native habitats there is a considerably larger rainfall during the growing season than here, but the deficiency could easily be made up by irrigation. The principal thing to be noticed about these Russian grains is that they are adapted to a short and cool growing season. Many have already been introduced, and others doubtless will be.

It may be interesting to note here that a colony of Russian Germans have settled in the vicinity of Mannhaven, where, by practicing methods of farming learned in their fatherland, they have been successfully tilling the upland soils for years. Good wheat, oats and potatoes, with all sorts of garden stuff, were seen growing on these seemingly arid upland flats, and potatoes were purchased in this region the last of July as good as could be grown in an Illinois garden.

Forage Crops.—Experiments with various forage crops at Brookings, South Dakota, have brought out some interesting facts. The selection of forage crops will become a matter of some importance when the flats of the river have been devoted to the raising of fodder. The possibility of a definite yield of provender for winter feeding is one of the best reasons for adopting irrigation. The following record of crops raised at Brookings suggests the range of possibilities for the valley lands:*

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* Bull. 52, U. S. Experiment Station, Brookings, S. D.

RECORD OF CROPS UNDER IRRIGATION

Crop	Date of Sowing	Yield Per Acre	Remarks
Peas	May 18	2.6 tons dry hay	Cut green
Onions	May 4	225 bu. per acre	
Brome grass	....	....	Very successful crop
Oats	May 7	1.68 ton per acre	Cut for fodder
Jerusalem corn	May 11	8.22 tons (green)	Cut for fodder
White Kaffir corn	May 11	18.12 tons (green)	Cut for fodder
Red Kaffir corn	May 11	18 tons (green)	Cut for fodder
Salzer's Superior fodder corn	May 11	25.6 tons (green) 9.2 tons dry	Cut for fodder
Early Adam's fodder corn	May 11	9.6 tons dry	Ears in milk stage by August 10
Alfalfa	May 18	... .	Vigorous growth
Clover	May 18	....	Excellent growth

From the results above tabulated one may readily read the possibilities for the production of forage crops along the flats of the stream already referred to. At the present time the yield of wild hay seldom exceeds a ton per acre, and is generally much less; further, the producing area can be mowed but once in two or three years. Compare this with the capacity of these flats to produce hay and other fodders. The writer has seen between three and four tons of blue joint grass per acre cut from such flats when under irrigation. If the land were plowed and sown to alfalfa or fodder corn, doubtless a much larger yield would reward the farmer. One of these flats well tilled would produce more than several thousand acres of the uplands which are scattered over tens of square miles of territory, reached only by rough roads of steep grade.

In addition to the excellent crops of grain and hay which these flats are adapted to raise, good garden crops are possible. Not only are these possible,. but as good garden stuffs as could be grown anywhere in Wisconsin or Michigan were seen during the summer trip. Tomatoes, lettuce, cabbages, potatoes, melons, etc., were ripe by the 5th of August.

Experiments at Brookings on garden truck show the following results.* Tomatoes mature between May 25th and July 22d. Nine varieties of cabbage seed were sown May 20th, and cabbage plants set June 25th. Celery plants, from seeds sown

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*Bull. 52. U. S. Experiment Station, Brookings, S. D.

April 9th, were set July 28th. The growth was excellent. "Giant Pearl" furnishes bunches four inches in diameter, averaging thirty inches in length. Hubbard squashes planted June 3d ripened well and averaged eight pounds each. Asparagus gives an excellent growth. Radishes and lettuce produce well.

With reference to the present condition of the grass crop of the plains and its possibilities under a system of irrigation, the following statement taken from Bulletin No. 6 of the Division of Agrostology of the Department of Agriculture, shows the importance of early attention to crops that supplement the grazing industry of this area.

The principal native grasses, Big Blue Stem, Bushy Blue Stem, Switch grass, Western Wheat grass, Western Quack grass, Slender Wheat grass, Fowl Meadow grass, Cord grass, Wild Rye, the Blue Joints and the various species of Stipa, the Gramas, Buffalo grass and Prairie June grass furnish most of the grazing. Blue Joints, Sand grass and Cord grasses furnish the hay in the moister bottom lands.

Overpasturing in time of drouth is killing out most of the grasses here, and unless this practice is abandoned, permanent injury will result to one of the most important natural resources of the west. It is important that every possible effort should be made to preserve the native grasses. They are naturally adapted to the conditions which prevail in this region, and it is quite improbable that introduced forms can be had to take their places satisfactorily, at least for years to come.

"Experience has shown that many of the most valuable native grasses are very much benefited by a judicious application of water. As a rule there is sufficient rainfall to give the grasses a good start in the spring, and if enough water could be had to keep up a strong growth when the dry, hot weather comes on, an abundant forage crop could be assured."

As an illustration of the truth of the above statement it may be said that the writer has seen some three hundred acres of river bottom land at the lower end of the Little Knife river north of the Missouri, under the application of water, producing between two and three tons of Blue Joint grass per acre. The Black Bros., by the expenditure of a few hundred dollars, have turned the arid, sun-burned soil, producing naturally grasses but a few inches in length, into hay fields where grass grows waist high.

In addition to the grasses, "Millet is extensively grown in some farming communities, and such recent introductions as Kaffir corn, Lupines and Arid Sand Vetch seem likely to assume an important place among the forage crops of this region, already so bountifully supplied by nature with the grasses of the field."

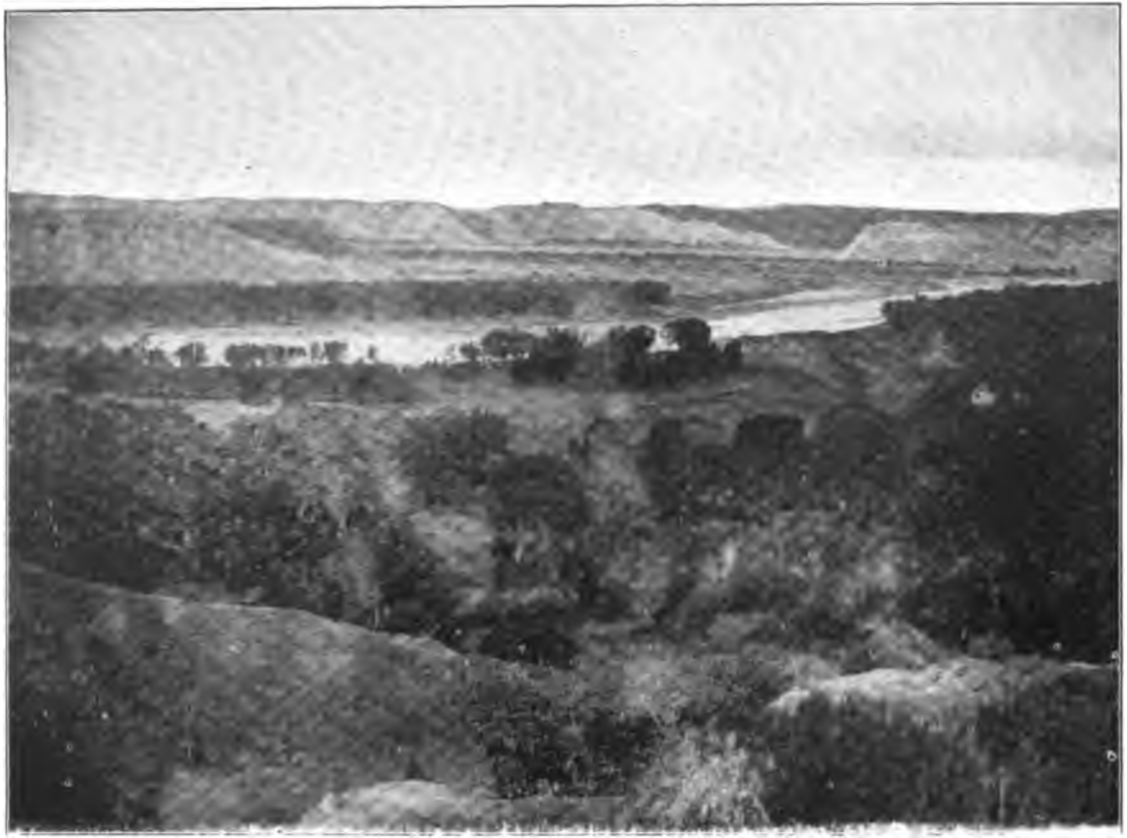
Tree Culture—Native Trees.—In the Little Missouri basin there are at the present time several thousand acres of forest land, either on the flats of the river, where cottonwoods hold sway, or in the protected ravines where ash and elm occupy the lower valley and cedars the upper slopes. Many of the bad land buttes have their upper north slope nearly covered with these low growing conifers, and the V-shaped ravines along the river are often crowded with the growth. The cottonwoods are found growing on the lower flats of the stream, and do not seem to be present on the upper sage flats; either they never grew here or they have been killed out by continued drought and the encroachment of the sage brush. It seems rather remarkable that there should be no trace of cottonwoods on the sage flats, which rise but a few feet higher above the river level than the wooded flats. The cottonwood, however, must send its root down to water, and if the distance becomes too great the tree suffers. The slow growing cedar, on the other hand, seems to absorb sufficient moisture from the porous soil about its roots in the ravines. It is not averse to moisture, however, for it usually attains the greatest growth down in the bottom of the draws. None of the trees lift their heads high above the surface of the ground, probably because their growth is cut short by the withering winds. Cedars have been seen three feet in diameter at the base and only fifteen or twenty feet high. A clump of such trees seldom rises above the edge of the protecting crest of the bluff. In very favorable localities cedar attains such a height that poles forty or fifty feet long may be cut. The cottonwoods develop spreading branches when they are free to grow large, and a clump of such trees appears much like elms in form. In places they are found two or three feet in diameter. It is an interesting sight to see the rows of cottonwoods, as they are frequently found, arranged in graded sizes along the river bank. Sometimes they form a fringe of shade along the bank of the stream only; often they form a belt extending along the depressed area in the center of a flat; again they grow large, and in dense forests occupy the whole flat except where bordered by younger trees on the recently formed banks; or finally the prettiest sight is that where the trees seemed to be arranged along either side of a recently abandoned channel, like shade trees by the road side. (Plate No. XIX.) Where they are too remote from water level the trees are dying out. In some cases fire has killed them off. In many places the space beneath the trees is occupied by a dense growth of shrubs, such as willows, buckbrush, wallberry, buffalo berry and wild roses, which often form almost impenetrable thickets.

The cedars furnish logs for building and for fence posts, for which purpose they are so well adapted that they are sought for by settlers many miles to the east of the area.

Along the east side of the Kildeer mountains there is a large growth of burr oak. Here this tree is preserved entirely by the protection afforded by the mountains. This fact is strikingly attested by the way in which the trees fall off in size toward the south side of the south mountain, where they quickly disappear altogether. They are not found in any case more than a mile to the east of the mountain, and at this distance only where they are protected by the foot hills. Not one lifts its branches above the mountain top, and they are entirely absent from the gap between the mountains and almost entirely lacking from the west side. The richest growth is found just north of Oakdale on the southeast end of South mountain. The presence of these noble trees, so rare in other parts of the Little Missouri valley, lends enchantment to this pretty group of mesas.

Along the valleys of Knife river and Spring creek trees are often entirely wanting. The prevailing growths here are the box elder and the ash, with a few good sized elms along the lower Knife. The box elder grows thick and bushy, with short, often partly prostrate, trunk and spreading branches. Like the cottonwood, this tree occupies the protected places along the stream, often, as it were, crouching down in the old cut-offs of the stream or in an abandoned gulch to avoid the too direct rays of the sun and the drying summer winds. Some of these trees were seen two feet in diameter and rising but twenty or thirty feet above the ground. Because of this stubby, branching growth they make excellent windbreaks, but do not afford much shade.

PLATE XIX



Flats of the Little Missouri between Morgan's ranch and the mouth of Beaver creek. An old channel appears in the center of the field, cottonwood forests along the stream

There are long reaches on both the Knife and Spring creek where all trees and even shrubs are absent. This is especially true of the upper parts of the streams. Among the larger growths the following well known forms are commonly found, the type varying greatly with moisture conditions:

Wild plum—*Prunus americana.*

Choke cherry—*Prunus virginiana.*

Gooseberry—*Ribes oxycanthoides.*

Missouri gooseberry—*Ribes gracilis Michx.*

Wild red cherry—*Prunus pennsylvanica.*

Service berry—*Amelanchier alnifolia.*

Dogwood family—*Cornus.*

Silver berry—*Elaeagnus argentia* Pursh.

Buffalo berry—*Shepherdia Argentia* Nutt. This is a native fruit producer worthy of careful attention. For jelly making the fruit has few equals. It is currant-like in form and grows in large clusters on a shrub which is found in extensive thickets along the Little Missouri river.

White birch—*Betula.* This is found in a few places, one of which is the vicinity of the Kildeer mountains.

Hazel nut—*Carylus americana*, near Kildeers.

Willows of many varieties—*Salix longfolia* and others. Many of them are sandbinders growing along the river.

Junipers—*Juniperus communis*, a small tree growing in the bad lands. *Juniperus siberia-procumbens*, a small creeping cedar. *Juniperus virginiana*—Red cedar.

Other growths so characteristic of the bad lands as not to be easily overlooked are the Cactus and Artemesia, or sage bush. The sage bush seems to be the growth that succeeds the cottonwood on the flats.

HYDROGRAPHY AND IRRIGATION

Stream Measurements.—A gauging station was established at Medora, May 12, 1903, by F. E. Weymouth of the U. S. Geological Survey. The following figures furnished by Prof. E. F. Chandler, assistant engineer of the State Survey, show approximately the flow of the Little Missouri from the time the station was established up to November 17, 1903:

RECORD OF GAUGING STATION FROM MAY 12 TO NOVEMBER 17, 1903.—MEDORA

Month	Average	Maximum	Minimum
May 12-31	950	2880 May 25	40 May 15
June	240	830 June 26	50 June 20
July	1080	3900 July 5	120 July 21
August	2300	4000 Aug. 6 6100 Aug. 31	900 Aug. 16
September	1240	5550 Sept. 1 2560 Sept. 20	180 Sept. 30
October	70	150 Oct. 1	40 Oct 27
November 1-17	75	100 Nov. 15	60 Nov. 5

Flow given in second feet.

The figures of the above table are not what one would expect from a study of the rainfall records of the area. We find here that while the stream had much more than an average flow for May, the maximum flow occurred during the months of July, August and September. Considering the fact that the rainfall passes rapidly to the channel of the river, it is evident that the heaviest rains came late in the summer for this year. That such is the case the observations of Mr. Foley, meteorological observer of Medora, show. He reports that the larger part of the

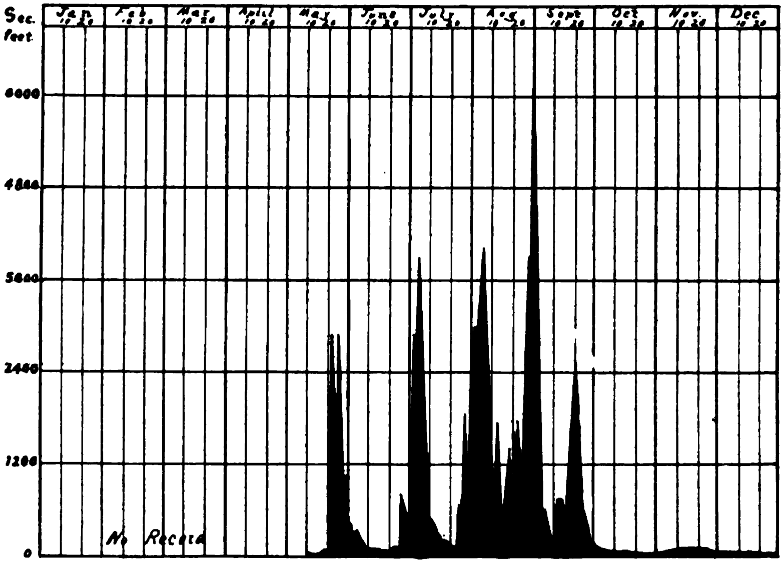


Fig. 3. Discharge of Little Missouri at Medora, 1903

A sage flat

rainfall comes usually in April, May and June, much earlier than in the summer of 1903. Further, that the winter supply of moisture is generally small, so that the river often freezes solid. This is not so remarkable when we recall that the river is but a few inches deep at the rapids during low water.

From the record of the gauging station, as well as from observations made during the summer, it seems probable that there will always be a sufficient supply of water in the Little Missouri for purposes of irrigation along its flats. While the flow of the stream at times becomes very small, the long reaches of quiet water between the rapids, not taken into account in the measurements of stream flow, would be capable of furnishing a large supply, should the actual flow of the stream cease for some considerable part of the summer. Having a depth of from one to ten feet, and being in some cases many acres in extent, these long stretches of standing water in the stream channel are natural reservoirs.

With reference to the use of the stream in irrigation several questions of much more importance than that of stream flow arise. Of first importance is the manner of appropriation. To answer this question it will be necessary to consider the character of the valley, including flats, slopes, nature and number of tributaries and natural fall of the river.

Flats.—An inspection of the relief map accompanying the report will show the relative position of the flats and stream channel. Plates X, XIX and XX show the situation and general elevation of the flats with reference to the bluffs of the river.

The flats are for the most part entirely discontinuous. They lie in the recesses of the valley between successive bluffs which form their upper and lower limits, and represent the area over which the stream has worked during an earlier period in its history. As a rule the flats alternate in position, and so are seldom found facing each other on opposite sides of the river, except along the straighter course of the stream for twenty or thirty miles above Big Gulch creek. The flats vary greatly in size and shape. They are generally triangular, approaching in many instances the shape of sectors of a circle, with the apex extending up draws in the rear. In width from river to bluff these vary from a few rods to a mile. The larger flats are found at the lower end of the creeks, and in these cases extend some distance up the creek valley. Flats of less than forty acres are not considered in this report. They slope gradually from the lower border of the buttes and bluffs to the line of the river channel where there is always an abrupt drop of from ten to thirty feet to the level of the water in the stream, which is usually found cutting along some portion of the vertical face of the flat.

The soil of these flats is almost altogether alluvial in nature, being the deposit of the stream at an early day or the wash from the adjacent slopes. It is usually of slightly coarser and more sandy material than the undisturbed strata of the bluffs, having a texture which is due to river sorting. The depth of this soil, as observed almost continuously along the stream, is nearly as great as that of the height of the flat above the channel. The surfaces of these flats are usually entirely appropriated by a rank growth of sage, or by low bushes, such as buck brush, wolfberry, and the like. The slope of the surface, both in the direction of the stream and from the bluffs to the river, is very slight; a fact which would be of great advantage in supplying water to the surface.

The creeks entering these flats from the rear cross them in deep, meandering channels, the banks of which support a dense growth of bushes of all kinds. The position of the flats with reference to the creeks is often such as to make it possible by damming, to turn part of the flow of the creek upon the flat. An effort has been made in one or two cases to do this.

The more recently formed flats are not suitable for irrigation; for, while their surfaces are nearer water level, they are very irregular, the soil is sandy, and for the most part they are covered with growths of cottonwood.

Below the mouth of Squaw creek the river cuts more nearly through the center of the valley, thus leaving long narrow flats on either side. In some cases, as below Warren's ranch, the flats are several miles long. In this part of the valley much slumping has taken place recently, which fact renders the surface extremely rough and unfits it for agriculture. There are a few good flats along the stream here, however.

Slopes.—The fall of the stream, on the average, is not more than four feet per mile. In some cases the flow for a mile or more is scarcely perceptible, such stretches being usually terminated by rapids with a fall of from one to three feet. Considering the moderate grade of the stream, the length of the flats and their height above the river, there is no case where the water could be successfuly diverted by a canal from the stream to the individual flats. In some cases, as already stated, the water might be carried from the creeks to the flat by this method. If dams of sufficient strength could be made to impond a part of the discharge from the creeks, they would become a source of rather a large supply of water.

IRRIGATION

Gravity Methods.—Methods of getting water upon the land vary greatly and depend upon the conditions found upon the individual streams. From the conditions already outlined for the Little Missouri there seems to be but one method of water supply possible for the flats in general, viz., lifting the water to the flats by pumping. The body of flat land is so scattered along the stream, that nowhere could a sufficient area be put under cultivation to make it pay to carry water by tunnel for several miles. Again, the construction and maintenance of an aqueduct of any length along this stream would be a very difficult piece of engineering. Canals running entirely on one side of the river would be subject to the constant undermining of the stream at the cut bluffs. If the canal were carried across the river from flat to flat, as would be necessary on account of the alternate placing of the flats along the river, there would be great difficulty in securing a stable foundation for the midriver supports, since there is no solid foundation to be had anywhere. Other difficulties would be found in securing stone for construction purposes, in seepage and consequent undermining in the fluent clays along the stream, and in the instability of the unconsolidated materials generally.

While diversion of water by canals from the main stream is probably impractical, almost all of the large creeks are so related to the flats at their mouths that the water might be diverted from them to supply a small acreage.

Water Storage.—The flow of the river during the season when water would be most needed, as shown by the record, is from 900 to 1,000 second feet. This is a quantity sufficient to supply all the water needed for 100,000 acres if the water were all used; that is, if none returned to the stream by seepage.

The estimated amount of flat land along the stream is 30,000 to 50,000 acres, or something more than 150 acres per mile. For the quantity of irrigable land it is plain that failure of water supply is not to be considered at all. The only places where water storage might be of importance is in the creek valleys. In some instances the narrowness of the lower part of these valleys would permit the storage of rather a large body of water, if sluiceways adapted to withstand occasional floods could be invented. The fact that the bottom lands of these parts of the creek valleys are alluvial, leads to ready seepage of water and consequent undermining of dams.

Methods of Lifting Water to the Lands.—There are in general five methods of lifting water to the level of the lands to be farmed:*

1. Pumping by animal power.
2. Pumping by water power.
3. Pumping by windmills.
4. Lifting by elevators or undershot wheels.
5. Pumping by steam power.

The peculiar conditions of this valley seem to warrant the success of any one of these methods, though there is but one of the five that would be applicable and practical everywhere, viz., pumping by steam. The flats lie for the most part not more than twenty-five feet above the river level, and even in time of least flow deep pools from which water could be drawn will be found adjacent to every flat.

There is little need for standing on the question of the sort of pumping that is to be used. There is probably no other valley except that of the Missouri, where, when other methods of irrigation are so entirely impracticable, there is such a fortuitous juxtaposition of flats and fuel. The abundance of lignite in this valley is truly remarkable, and its distribution is of such a character as to render it easily accessible to any flat along the stream. Coal seams at one elevation or another run almost continuously from Medora to the Missouri. Few miles of the river were passed where coal outcrops two or three feet in thickness were not constantly in view; and several seams varying from two to eight feet were followed at times for ten and fifteen miles together. As the abundant fuel has been the life of this western land so far, it is possible also to make it the means of giving more life by employing it to raise water for the thirsty flats. If pumping as a means of irrigation has been found to furnish water generally more cheaply than gravity sources,* in regions where fuel is scarce, it seems a reasonable thing to expect that the same method could be applied in this valley to great advantage.

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*Wilson. Manual of Irrigation Engineering.

There is another consideration that must not be lost sight of. As already stated under the head of climate, a large part of the rainfall may be expected during the growing season, at least several inches even in the most unfavorable years. This fact makes the resort to artificial methods of supply merely a supplement to rainfall and not the whole resource. Without any other than the ordinary rain supply fairly good crops are secured by dry farming, and it seems probable that, were there the inclination, dry farming would be as successful here as in any part of North Dakota. It follows then, that the cost of fuel for pumping being almost nothing, the cost arising from care of an engine would be greatly lessened from the fact that continuous pumping would not be necessary; and at intervals, when other work was not pressing, all hands could be set to work to flood the land in need of water. For this reason it seems practical for both ranching and farming, the one as a complement to the other.

Another advantage that would result from such a method of irrigation is that each man could not merely own his land, but could control absolutely the water supply. There need be no litigation over riparian rights, or priority of use of water, or from difficulties of seepage, matters that so impede irrigation in some of the other states of the west. Few of the flats are larger than the needs of one man require.

Pumping by windmills might be practical for small areas, such as gardens. The difficulty with windmills arises from the fact that the wind cannot be depended upon. Further, with winds blowing steadily, which is far from the case here, the surface of the valley flats is so much below the bluffs--300 to 500 feet--and the valley so narrow, that the full effect of the wind is not felt. Twice only during the summer did the party on the river encounter high winds, and in both cases the wind blew in the direction of the valley. The wind velocity is not more than nine or ten miles an hour at an average on the upland surface, and must be much less in the valley. The capacity of an average windmill in irrigation is from one to three acres; but if accompanied by storage reservoirs, from three to five times this amount. There are numerous mills in the west that irrigate from ten to fifteen acres. Wells thirty to 150 feet in depth supplemented by storage tanks furnish the water. These, including mill and tank, cost from $150 to $350.

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*Wilson, Irrigation Engineering, p. 456.

Lifting by Means of Undershot Waterwheels.—There are some areas along the stream that might be watered by the aid of the undershot wheel. It would, however, be found difficult to maintain a foundation for the support of such a wheel; and further, if it were once placed, the shifting of the channel and undermining of parts of the support would make frequent readjustments necessary.

Lifting by Pump.—This is not the place to enter upon a discussion of the efficiency of different classes of pumps, but it may be of interest to state what their capacity with reference to irrigation may be. In this valley the lift may be taken, on the average, as twenty-five feet and the pump used will brobably be some one of the centrifugal or rotary forms.* The following illustrations show something of the capacity of these pumps:

A centrifugal pump on a farm in southern Arizona, operated by a ten-horse power engine, has a capacity of two-thirds of a second foot per day, or is capable of irrigating three to five acres in a season. A similar pump in the same locality operated by a thirty-five horse power engine handles eleven and one-half acre feet, or about six second feet per day of twenty-four hours. This would irrigate in North Dakota climate, from ninety to 160 acres.

Knife River and Spring Creek Basins.—A gauging station was established at Broncho postoffice by Mr. Weymouth May 29, 1903. Since that time the flow in second feet past that point has been approximately as shown by the following table:

Month	Average	Maximum	Minimum
May 29-31	75	May 25, estimated, between 2,000 and 4,000	
June	30	(June 8) 64	24
July	58	(July 27) 840	(July 25) 16
August	45	(August 29) 311	(August 9) 16
September	62	(September 15) 217	(September 21) 13
October	12	13	11
November	10	13	9

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*Wilson. Irrigation Engineering, pp. 469 and 494.

The length of the Knife valley is not far from one hundred miles. While irrigable flats do not border the stream continuously, their extent is between 15,000 and 25,000 acres. If the quantity of water allowed per hundred acres is a second foot, it will be seen from the table that the average flow would be far from sufficient to supply the entire area possible for irrigation. Should a part of the flood supply of the summer months, however, be conserved in reservoirs, the supply would be ample. Any system of irrigation that is adopted must be conducted with reference to this fundamental fact. The relative decrease in the supply falls off toward the head of the stream, as above Fayette, where the river, it is understood, often goes dry in the midsummer. Enough water would be retained in the pools toward the middle and lower course to last through the dry season, and the quantity could be easily increased by partially damming the stream at points of diversion. Possibly in this way, for the larger part of the stream, no other sort of reservoir would be necessary. The channel is for the most part canal-like, varying in width from twenty to sixty feet, with a depth of from ten to thirty feet. It meanders through the valley rather widely, so that a single low dam could be constructed, by a few

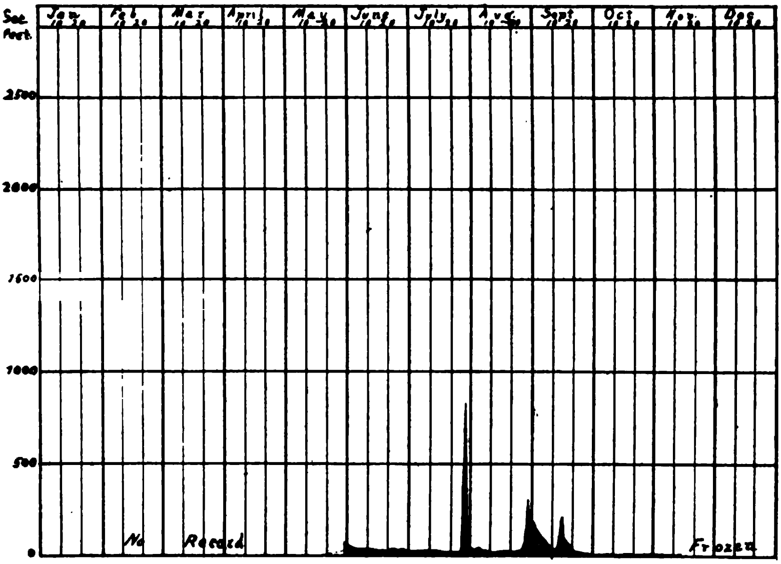


FIG. 4. DISCHARGE OF KNIFE RIVER AT BRONCHO, 1903.

days work, from the abundant boulders and burned clay found along the valley.

With reference to methods of furnishing water to the land, the conditions, generally speaking, are the same as for the Little Missouri. However, the difficulties that would be encountered on the Little Missouri from bluffs, undermining, etc., in canal building, are absent from this valley; and there is also an abundance of material for ballast, and no serious obstructions along the valley sides. Furthermore there are continuous stretches of flats for twelve miles from the mouth of Crooked creek to J. K. Slack's house in Tp. 142, R. 93, Section 12, and for fifteen miles between Hazen and Stanton, that could be brought under the service of single canals. The size of the flats above mentioned is as follows: From the north of Crooked creek to J. K. Slack's, 2,500 acres; at mouth of Spring creek 1,000 acres; below the mouth of Apple creek at Hazen and Stanton 3,000 to 4,000 acres. There is another stretch of 2,000 acres between Shaffner's ranch and Broncho that might be added to the above list.

The flow of the stream below the mouth of Spring creek must be greatly increased; and it is probable that the added supply from the creek would be sufficient for the flats below this point.

Spring Creek.—Spring creek meanders through flats for a distance of fifty miles. The total amount of irrigable flats is probably 5,000 or 6,000 acres. This is not uniformly distributed, however. For the first twelve miles the flats are extremely broken, small and often of rough surface. From a point a few miles below Halliday the flats begin to widen out, and in places for the next fifteen miles are from a half to three-fourths of a mile wide. Their surface is flat, the soil good, and the elevation above the creek not more than twenty feet. Along the head branches of the creek there are some very large flats which are so near the stream level as to be partly inundated in wet periods.

The flow of Spring creek seems to be much more regular than that of the Little Missouri, and it carries on the average nearly as much water as the Knife. The evenness of flow is due to the drift material covering the slopes of the stream. The supply seems to be sufficient for all the irrigation possible in the valley. Pumping by steam would be as practical on this stream as along the Little Missouri.

Farmers Valley.—Farmers valley is the name given to the rather peculiar valley lying north of Taylor and Richardton, and extending from the head of the Deep creek valley to Hebron, a distance of twenty-five miles. There is no reason why the name should not include the valley of Deep creek, since that is continuous with Farmers valley, and of about the same width and depth. The Little Knife valley, running to the Knife valley north of Richardton also seems to be a part of Farmers valley. The amount of flat land in this series of valleys, between Rock Spring and Shaffner's ranch near the mouth of Little Knife, must be between 8,000 and 12,000 acres. The valley varies in width from one-half to two miles; the flats lie ten or fifteen feet above the creek level, and have rather a smooth surface, and in most places excellent soil. Dry farming is practiced at several points along the valley, both on the flats and adjacent rolling uplands. Deep creek carries enough water, if it is conserved by dams, to supply the land along its portion of the valley; likewise Little Knife has enough water below the junction of the two creeks north of Richardton. With reference to the ten or twelve miles of the valley north of Richardton and Taylor, it is doubtful whether the water supply can be greatly increased over rainfall, since the flats are nearly as wide as the receiving basin of the valley. Near the head of this stretch of flats, southeast of Gunwall's house, there are several large sloughs that might be used for reservoirs. The valley north and west of Hebron was not visited, but from the appearance of the wide flats at the lower portion of that section of Farmers valley it is probable that they continue for some miles at the same width. If the state map is correct, the meandering of streams shown in the eastern part of Farmers valley, and of Little Knife valley, suggest rather flat, open valleys, where water storage by dams would be a simple matter. Further, it seems quite possible that the twenty miles of the valley between Hebron and the Knife river, and a section of the Knife valley, and the twelve miles between Shaffner's and Broncho, might be put under a single system of water supply. There must be 8,000 or 10,000 acres in the flats along this distance of thirty miles. The other tributaries of the Knife river, those on the south side east of the Little Knife, were not seen. It is probable that there are a few good irrigation sites at the lower end of these smaller valleys.

Coal Along Knife Basin.—Coal is just as abundant in this basin as in that of the Little Missouri. Heavy seams are found along the river in both the upper and lower valleys of the stream. Six miles west of Halliday a seam sixteen feet thick of solid coal extends over a large area, lying with its base a few feet below the level of Spring creek. Other seams of from four to eight feet in thickness outcrop at numerous places along the creek below this point. The same abundance of coal was found along Knife river and Farmers valley. The maximum haul of fuel for a steam pumping engine would not be more than a few miles in any case, and, as on the Little Missouri, the engine might in many cases be set up at a coal bank.

OTHER ADVANTAGES OF IRRIGATION

Aside from the aids to irrigation on these streams already mentioned, abundance of coal, moderate elevation of flats above the stream, ease of constructing reservoirs, lack of occasion for expensive litigation over water rights, fertility of the soil, etc., there are other advantages that should be emphasized. Not the least of these are those that pertain to farming generally in the Dakotas. Crops once matured may stand outside after harvest until threshing is done, since the dry air and absence of rain make that a good method of curing grain. This makes the building of large barns unnecessary. Hay keeps well in the stack on account of the dry fall and winter. Stock can be pastured on the uplands far from the growing crops in the valley, and require little attention during the time that the farm crops need care. During the long, dry fall there is much time during which repairs could be made in the irrigation ditches and sluiceways. New ditches could be made and more land brought under cultivation.

But the point of greatest importance in connection with irrigation here is this: The fact that the uplands along the stream are too rough for farming, while they furnish excellent grazing, makes them naturally a supplementary resource for the farmer who owns land adjacent to them in the valley, and for this reason should be reserved accordingly. Along the Little Missouri, especially, is the relation between flats and grazing very close. Here the bluffs divide the belt of flats into sections of from 100 to 300 acres each, distributed at intervals of a half mile or so along the stream. No farming on the uplands in the rear of these flats is possible. This gives the owner of a flat control of a strip of land a mile or more in width, and extending back to the divide from five to twenty miles away. The strip of grazing land is rarely twice this width, since the flats alternate along the stream. This combination of grazing lands and irrigation possibilities in the area is its most hopeful feature, and it is probable that irrigation will always go hand in hand with stock raising in western North Dakota. The added certainty of a supply of winter provender for stock through irrigation, will make grazing a much surer occupation, and lead to a more systematic use of resources of the higher plains. Though the introduction of farming into the area may multiply the number of head of stock per township, and thus reduce the size of the herd, the added variety due to the new occupation will increase the range of life for man, make the area more populous, bringing in better homes and eventually open up the immense resources of clay and coal in these river valleys. There is no reason why the region from the Montana line on the west to the Missouri on the east should not support a population ten times the present number.

LIGNITE

Distribution.—There is no level as yet determined, where lignite seems to be more abundantly present than at another, and no large area from which it is entirely absent. It seems to be present everywhere, being almost as constant and persistent as the layers of the varicolored clays which form the larger part of the Laramie. The depth of strata observed in the area between the Missouri on the east and the western divide of the Little Missouri is about 1,100 feet, or the difference between the elevation of Bismarck, 1,618 feet, and that at the western part of the state, nearly 2,800 feet. Throughout this depth the materials are mainly light gray or yellow clays, thin beds and irregular concretions of sandstone, with some layers of limestone, concretionary quartzite, locally much fine-grained, stiff, sandy clay, and lastly the lignite seams. The number of thin coal seams in this depth of strata is large, since they occur at all elevations. The number of workable seams, assuming three feet as the lower limit, would be from fifteen to twenty. Large seams were seen at the following levels, approximately:

	FEET
Dickinson	2,380
Medora	2,240
Medora	2,260
Medora	2,300
Burgess'es	2,200
Mikkleson	2,160
Mikkleson	2,200
Beaver creek	2,120
Bolan creek	2,000
Halliday	2,000
Magpie creek	1,900
Near southwest corner of Indian reservation	1,800-1,900

Thick seams have also been found in the vicinity of Sentinel and Square buttes at elevations above 2,800 feet.

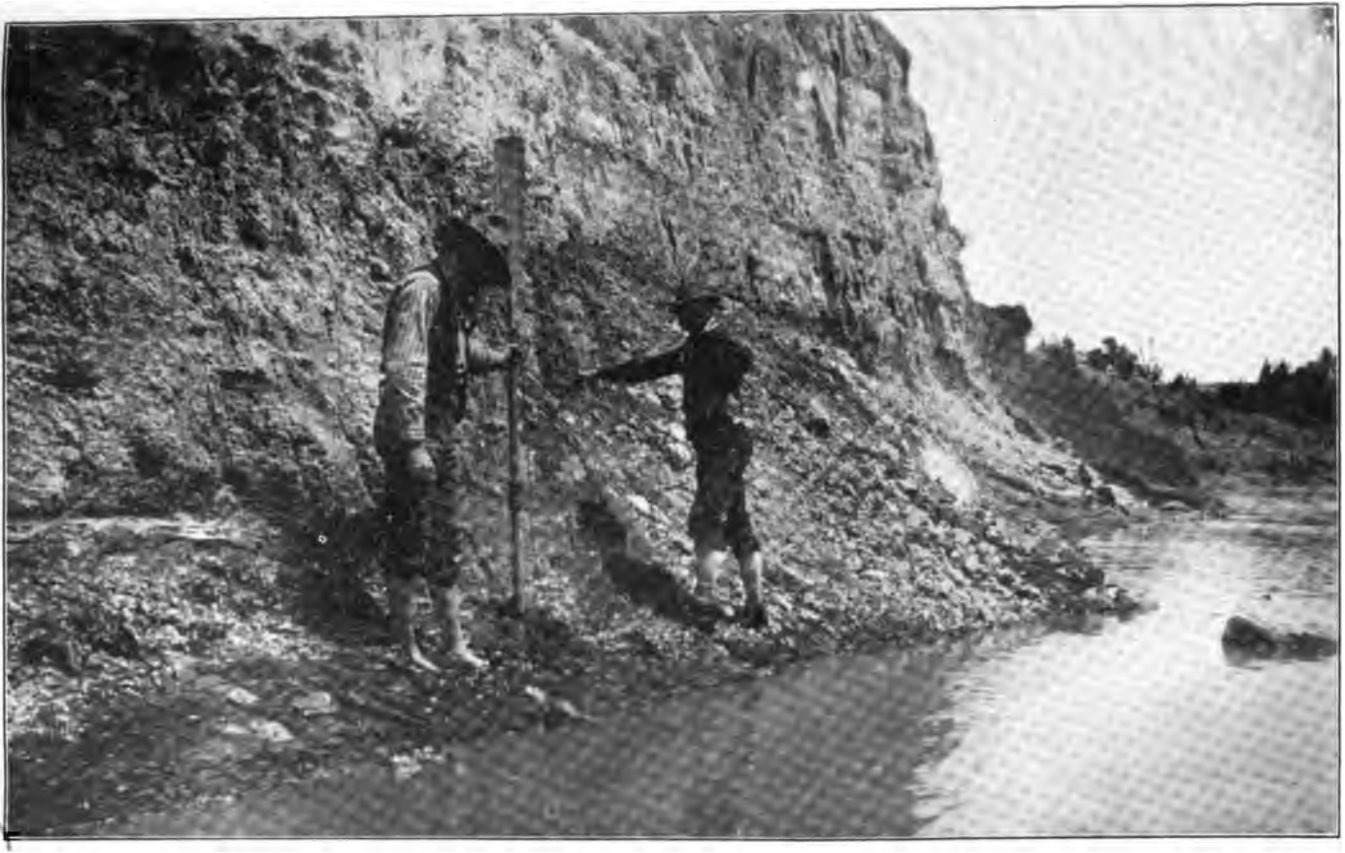
Of thin seams, as many as fifteen were counted in a single bluff along the river. These are significant, since they show that conditions for the formation of coal occurred many times in the same area.

REGIONAL DISTRIBUTION

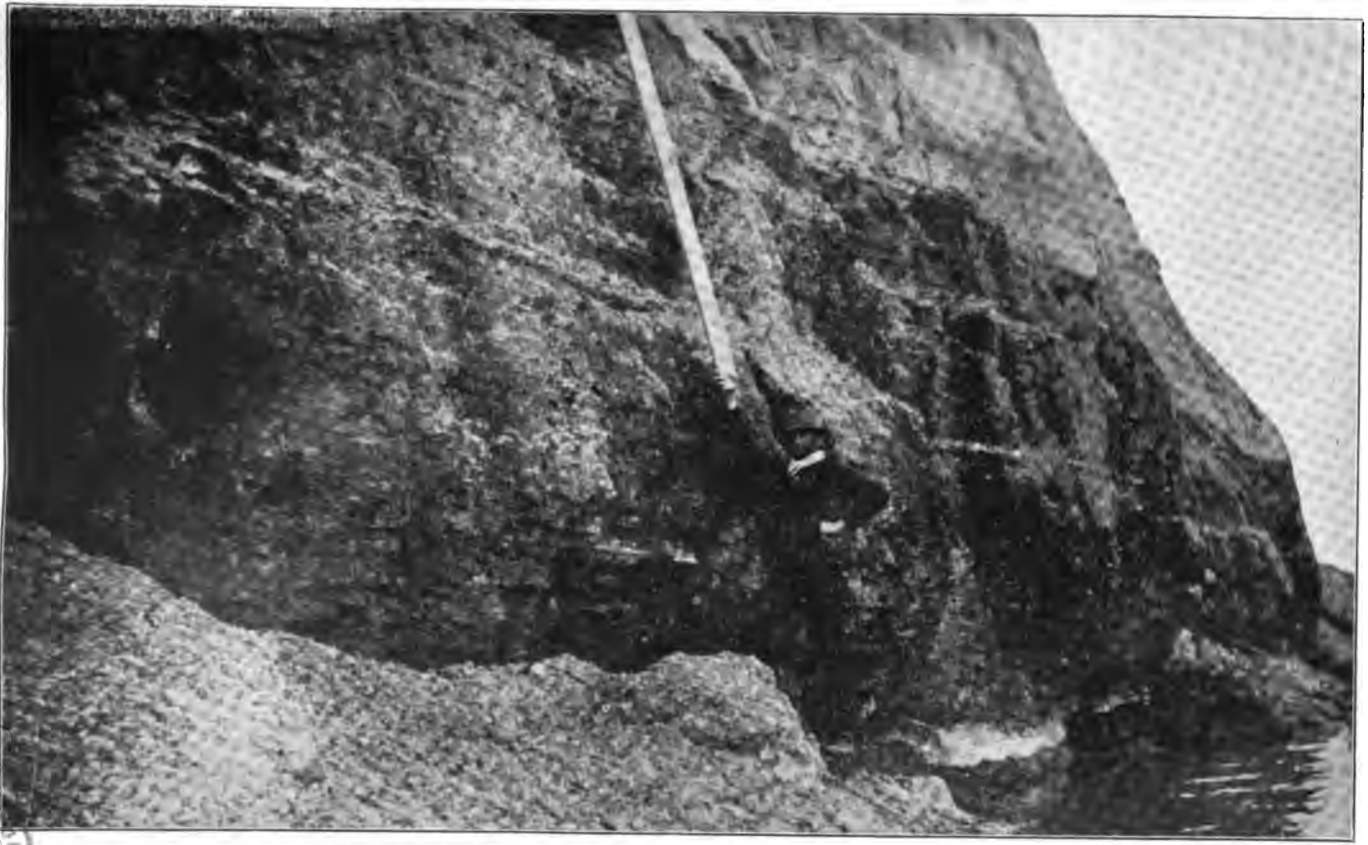
Little Missouri Valley.—Since coal seams of workable thickness were almost constantly in sight throughout the course of the valley for 150 miles, we will mention in this place only those localities where coal was observed to be unusually abundant.

At Medora several good seams are in sight, one of which, near the base of the bluff, is eight feet thick. Four miles north of Medora, opposite Mr. Burgess'es house, an eight-foot seam appears just above low water level, while a three-foot seam lies eighteen feet above. (Plate No. XXI.) A seam ten feet thick was seen in the hills at the head of one of the creeks three miles east of Mr. Burgess'es house. Five miles below this place two seams of three and five feet lie interbedded between strata of sandstone. Beds in similar relations were seen near Roosevelt's old ranch below Mikkleson. Four miles from Young's ranch, ten miles north of Medora, a ten-foot seam of coal was found burning. From the appearance of the burned clay in the area, this seam was at one time very extensive, probably to be correlated with the ten-foot seam seen at Burgess'es.

For several miles above Mikkleson good seams of coal appear in the banks. One of these, a two-foot seam, continues quite persistently at water level for a mile or more. Plate No. XXIII. shows a splendid outcrop of four seams, aggregating about six-



Coal outcrop, eight feet thick, opposite Burgess' ranch, five miles north of Medora



Coal seam sixteen feet thick, two and one-half miles below Mikkleson

teen feet in thickness; over which the covering for a considerable area is not more than fifty feet.

Three miles below Mikkleson a seam sixteen feet thick outcrops in a low butte, half of which has been cut away by erosion. (Plate No. XXII.) The presence of burned clay in the bluffs two miles west of this butte indicates that this seam is very extensive. It is probably the equivalent of the four seams seen south of Mikkleson.

In the vicinity of Read's ranch, besides the seams in the river bluffs, others were seen in the draws extending south from the river; while nearly due west of this point, in the valley of Beaver creek, seven or eight seams, the thickest being three feet, were noticed in several places.

Good seams of coal outcrop in the bluffs opposite Morgan's house, one being ten feet thick. All along the river, both above and below this point, for several miles, two seams, varying in thickness from two to four feet each, were constantly in sight. In fact these two seams were observed continuously for a distance of twelve miles from a point above Read's ranch to near the mouth of Cinnamon creek.

Near the mouth of Bolan creek and again at Redwing creek, a fine outcrop showing a ten-foot seam about a hundred feet above the river level was observed. Other seams of smaller dimensions were also seen here.

Along the course of Squaw creek and in the ravines opposite the mouth of the creek on the east side of the river, a seam thirty-four feet thick was observed. It is probable this is the same that acts as a water-bearing layer to furnish the springs at the X ranch on the head of Squaw creek.

Several miles below Warren's ranch, and almost due west of the Kildeer mountains, several good seams of coal were observed, and small seams at as many as eleven different levels. The seams below this point about the Diamond C crossing are at a considerable elevation above the river. No coal was seen at the Kildeer mountains.

Abundant supplies of coal are reported to exist near Shaffer's ranch on Cherry creek.

A very good seam of coal was encountered in the valley six or seven miles north of the Kildeer mountains. Here slumping has carried great blocks of coal into the river which appeared like black boulders as seen in the distance. A seam about eleven feet thick outcrops near the mouth of Jim creek and further down opposite Partridge brothers' house, where it had a thickness of eight feet. Just above Manning's old ranch the seam was found burning. Several good seams outcrop along the river below the corner of the Indian reservation.

STRATIGRAPHIC RELATIONS

The coal seams along the Little Missouri lie nearly horizontal, and are for the most part bedded between sandy clays. Sandstone occurs both above and below the coal at several outcrops. The contacts between the coal and the beds above and below are generally sharp. The clays are slightly discolored at some points below the coal by the remains of roots, and in one place a stump was seen rooted in the clay beneath the coal. At several points the coal graded off above and below to carbonaceous shale which, in places, was several feet thick. Now and then several seams merged into one heavier seam, but generally the thickness of the seams remained quite uniform over great distances. Frequently considerable quantities of petrified material occurred where it had weathered out at the upper surface of the coal. Stumps and logs that had fallen from them were often found at the coal horizons.

The various strata of clay lie nearly horizontal, so that the river channel falls continually lower with respect to particular layers of clay as it extends to the north. The bluffs are from 200-300 feet high at Medora, while north of the Kildeer mountains the level of the upland plain is between 500 and 600 feet above the river level. Due to this persistence in horizontality of the respective layers it is possible to roughly correlate the seams at several different horizons. Thus in the table below six different elevations are given at which considerable quantities of coal were seen.

ELEVATION OF COAL HORIZONS WITH RESPECT TO THE RIVER LEVEL BETWEEN MEDORA AND THE MISSOURI RIVER ALONG THE VALLEY OF THE LITTLE MISSOURI

MEDORA TO BURGESS'ES FIVE MILES

		Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
	(a)	Medora	8 feet	50-60 feet above river		Seven rods		Eight seams of coal reported from this point
		4 miles north of Medora; Burgess'es Ranch	10 feet	225 feet above river	Clay	Two rods		This seam probably represents a horizon above that of the seam at Medora
			(Note—As observed 7 miles north at elevation of 250 feet, the seam was largely burned out.)					
	(b)	Burgess'es	1 foot to 5 feet	About 100 feet				Probably the several seams represent the seams at Medora

BURGESS'ES TO JOHNSON'S RANCH

	Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
(a)	Opposite Burgess'es house.	3 feet to 8 feet	At river level and 16 feet above	Clay	Several rods	....	....
(b)	5 miles below Burgess'es	3 feet to 5 feet	20 to 30 feet above river	Clay and sandstone	At intervals for miles	Much sandstone in this vicinity	Strata undulating somewhat
(c)	Near Young's ranch	2 feet to 4 feet	40 to 60 feet above river	Clay	Seen in the ravines	Shell bearing clay 40 feet above the coal	....
(d)	Between Young's and Johnson's	....	....	....	....	....	Several thin seams, only, observed in the cut banks

MIKKLESON TO BEAVER CREEK.

B Probably represents one basin.	(a)	3 miles south of Mikkleson	2 feet	Lies at water's edge as the margin of a large flat	Alluvium above	1-2 miles	Fossil bearing clays 100 feet above	Probably other seams cut away above by the river
	(b)	1 mile south of Mikkleson	4 seams total 16 feet	All seams above water level. Lowest at water level	Clay—thin covering	50 rods	Bluffs cut away above	The lower seam may be equivalent to (a)
	(c)	2½ miles below Mikkleson	16 feet	Bottom 2 feet above water level	Clay	15 rods —1 mile below— 10 rods	Fossil bearing clays 1 mile east of the outcrop. Elevation 150 to 200 feet	Many places at this horizon where coal is burned out
	(d)	Read's ranch 7-8 miles north of Mikkleson	(1) 4 feet (2) 6-7 feet	(1) In bluff 60 feet above river (2) In draw 50-60 feet above river	Sandy clay	(1) ⅛ mile Seen at all the cut bluffs along the river below Mikkleson	Many shells found at elevation of 150 to 200 feet	Sandstone below coal in some places

BEAVER CREEK TO BOLAN.

		Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
C Probably represents one basin. Distance 12 to 15 miles.	(a)	7 miles west of Read's ranch on Beaver creek, 10 miles above mouth	Aggregate 10 to 12 feet	In cut-banks along creek seen at several points	Four seams separated by clay and sandstone	20 rods and ½ mile	....	A 10 foot seam was reported from this vicinity
	(b)	½ mile north of Read's ranch	3 feet	Lies under sandstone at river level	Sandstone above	Seen at several points for a mile or more	Probably lies 60 feet below the seam (d)	Two thin seams above this, may represent the seams at Read's
	(c)	Opposite Morgan's ranch, 6 to 7 miles below Read's	6 to 8 feet	Lies 20 to 30 feet above river level	Sandy clays above. Clays containing iron sulphide concretions below	4 rods	Clays—150 feet above shell bearing layer	Two other seams below this one, of 2½ and 3 feet respectively
	(d)	Just above the mouth of Beavor creek	3 and 4 feet	30 to 40 feet above river level	Sandy clays	One mile	200 feet above much concretionary sandstone; 60 feet above limestone, 2 feet, with fossil leaves	These seams were followed 6 miles down the river

BOLAN TO SQUAW CREEK

D	(a)	14 miles north of Beaver creek near Bolan creek	3 feet 4 feet 5 feet 10 feet	At several levels between 80 feet and 90 feet above the river	Clays, sandy clays	Several rods in each case	Many large fossil stumps at the horizon of the upper seams	The lower seam represents another basin. The upper three probably represents basin C
	(b)	6-7 miles below Bolan creek, Redwing creek	10 feet	100 feet above the river		Several rods		Probably the same as the 10-foot seam at Bolan Creek
	(c)	6-8 miles below Redwing, Squaw creek	Coal 5 feet Shale 4 feet	150 to 200 feet above the river	Sandy clay	Several rods	Much fossil wood at the coal horizon	Seam at same elevation at head of Squaw creek 6 miles to west. Seam runs on at high levels for 10 mi. further north

		Location of Outcrop	Thickness of Seam	Elevation of Outcrop with Respect to River Level	Materials Above and Below Coal	Extent of Outcrop	Characteristic Strata at the Coal Horizon	Remarks
E Probably one basin. Distance 10-15 miles	(a)	10-12 miles north of Kildeer Mts.	11 feet	Just at river level	Clay	10 rods	....	....
	(b)	Near mouth of Jim Creek	6 feet to 8 feet	At river level	Clay	5 rods	....	....
	(c)	2 miles below Jim Creek	8 feet	At river level	Clay	20 rods	Much petrified wood in slab form above coal	A very handsome outcrop
	(d)	3 miles below [c] at Manning's Ranch	6 feet to 8 feet	20 to 30 feet above river	Very fine firm clay	40 rods	....	This coal seam is burning
	[e]	3 miles below Manning's Ranch	5 feet	40 feet above river	Yellow clay	Several rods	Several other seams in the bluff above this one	Seam probably extends several miles further

We have stated the distances through which especially marked seams are known to extend, but these figures are not to be taken as representing the limits of the seams in a north-south direction, since they undoubtedly extend much farther. Whether the east-west extent is as great as the length of outcrop from north to south it is impossible to say; but, considering the longitudinal trend of the stream, it seems probable that this unknown dimension must be many miles in length.

From the extent of these different seams we conclude that the basins in which the coal was formed were very extensive marshes, having an area of hundreds of square miles in some cases, and lying so flat for long periods of time that a bed of vegetable remains twenty to fifty feet thick was able to accumulate. There were undoubtedly many areas within and on the borders of these marshy lands sufficiently high above the level of the water in the marshes to support a growth of mesophytic plants and forests. As portions of the marsh became dryer at certain seasons the trees would advance upon the territory of the marsh plants, and again with the return of wetter periods these trees would be killed and their trunks fall, later, into the mass of marsh plants to increase the material later, to be formed into coal. Such a mutual transgression of the various plants inhabiting the marshy regions would be apt to occur many times while the depth of forty feet or more of coal-forming materials was in process of accumulation, and thus logs as well as smaller vegetation would naturally be found mingled in the coal seams.

We find it difficult to realize that such large flats could exist so long a time, at so many intervals during the long Laramie epoch. But there are several reasons, some of which are worthy of mention, why this was the case. The conditions found in this region, it is believed, prevailed generally throughout an area 1,000 miles in length from north to south and two hundred miles wide from east to west, extending from New Mexico far into Canada, and about equal distances on both sides of what is now the Rocky mountain belt. In this broad inland basin sediment went on accumulating for long intervals of time, but not uniformly over the whole area. Land at many points lay so near the water level that vegetation was able to take root and to grow so abundantly that river sediments were shut out of considerable areas for periods of time sufficient to allow the accumulation of tens of feet of peat and bog materials.' We may suppose that this vegetable matter was accumulated much as it is today in the great cypress swamps or in the glacial lake beds that are found in such large numbers in Michigan, Wisconsin and Minnesota. The dense growth of forests, irregularly distributed over the area, furnished a protection from winds that would otherwise scatter loose sands far and wide, while the smaller vegetation acted as a strainer to keep out the fine material that might drift toward the bogs from movements of water currents. Thus almost pure vegetable material could accumulate, and of such the beds are found to consist today.

The materials found in the Laramie beds ot this area have generally a very fine texture, either clays or sandy clays, such as would accumulate under the influence of weak currents in wide shallow basins. The absence of coarce sands and gravel means either that the river entering the area lacked the turbulence of streams issuing from mountain regions, or that peripheral areas from which the stream gathered this material were low and pretty thoroughly disintegrated. If the land was low and marshy it is probable that the streams had but small velocity as they meandered over the region, and for that reason would not be able to carry large masses of drift logs and vegetation as some have assumed that they might have done, thus becoming agents in the accumulation of vegetable materials to be later buried and converted into lignite. In many cases, also, the areas of vegetable accumulation existed for long periods of time practically uncontaminated with clays.

The surfaces of clay and sand upon which the vegetable deposits were made, would be quite smooth and flat. When the water over these flats became shallow, due either to deposition or to the sinking of the water level, vegetation could rapidly take possession, creeping forward to appropriate areas as rapidly as conditions for plant growth became favorable. As some patches rose a little above the critical level for tree growth, forests would spring up, adding variety to the hitherto flat mass of bog plants. Most, if not all, of these hydrophytic forest trees would send their roots out laterally where they would penetrate the mass of peat formed by the earlier growth of the plants. Like marsh trees today, they would not have a very firm hold on the earth beneath, and would be easily toppled over by strong winds.

The occurrence of seams of coal one above another may be accounted for by periodical sinking of the area containing the coal forming basins. But it is likely another process has been in operation, the effects of which have been added to that of sinking. Bain* has shown that the great decrease in thickness which takes place during the change from peat to coal, the coal having but one-tenth to one-fifteenth of the volume of the peat, gives rise to several striking though natural results. The significant point in his discussion, so far as this report is concerned, is that the gradual subsidence of the area would furnish ideal conditions for the further deposition above, and that the coal basins would tend to perpetuate themselves. Given conditions for the formation of one bed of vegetable matter, when this is covered by a thick layer of sediment, it will surely settle through a depth equal to the difference in the thickness of the bed of vegetable matter and the resulting bed of coal. The settling of this bed of vegetation will go on gradually not only while the bed is still uncovered with sediment but also for a long period after it has been buried. It is evident then that when the surface once more is found near water level, and plants have taken possession, the bog will slowly settle, making it possible, without the necessity for general sinking,for plant remains to go on accumulating under the protection of bog waters. It seems quite probable that where there were such wide areas of marshes this factor of settling must have been very effective in bringing about conditions for the formation of numerous coal seams.

It is probable, also, that the coal was formed in situ by the growth of bog-forming plants much as peat is forming today. Bordering these bogs, and growing on them in many places, were forests of shallow rooting trees, which from time to time were added to the smaller vegetation of the bog. The thin clay seams observed in many of the coal seams may be the result of a rise in the water level as well as of a slightly more rapid rate of sinking rather than of plant accumulation.

Analysis reveals but little difference in the nature of the coals throughout the whole area. This is probably due as much to the impervious nature of the materials as to the lack of any extensive deformation of the region, or to the fact that all the seams are, geologically speaking, of nearly the same age. The difference of a few hundred feet in thickness of covering has had

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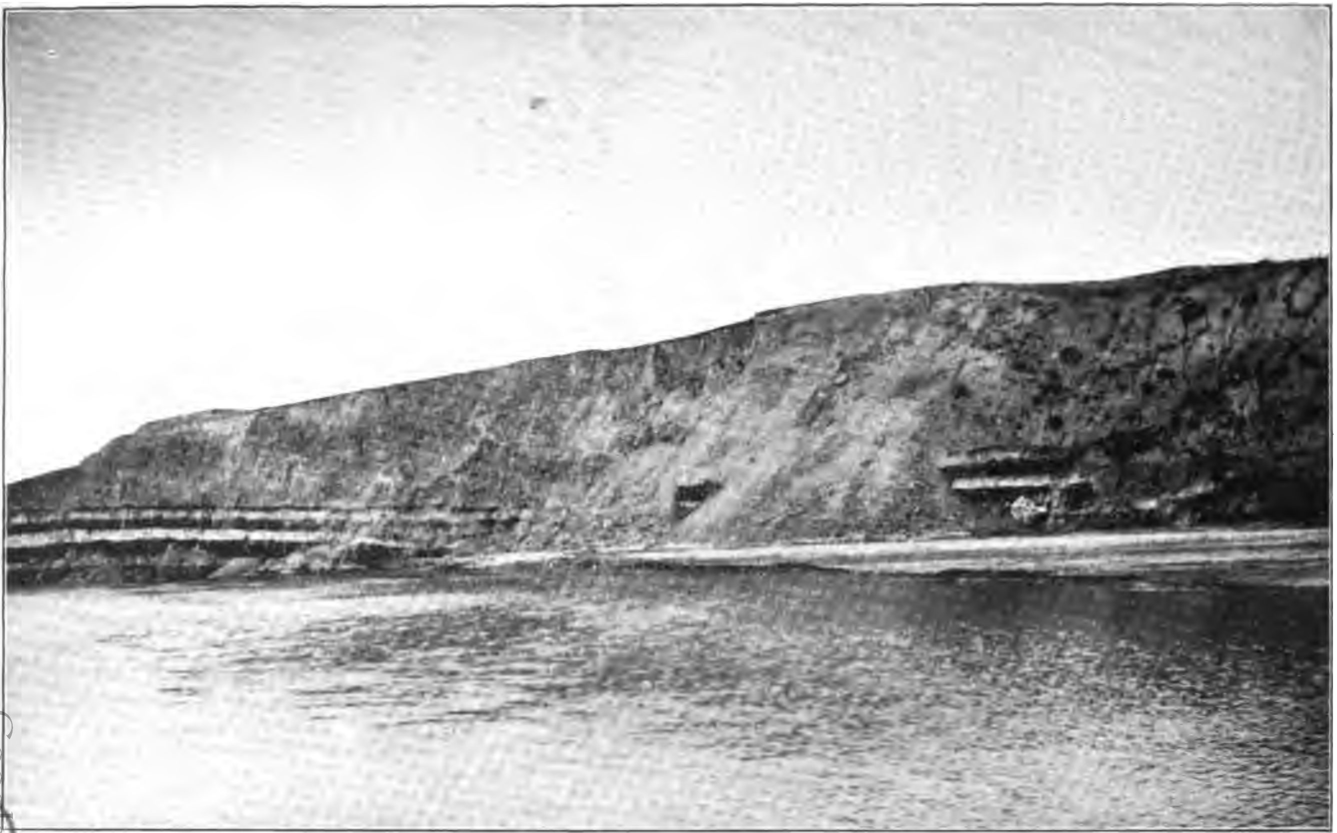
no effect whatever in producing difference in hardness. Coals from one horizon are as good as those from another.

Accessibility of the Coal.—For a long time to come, much of the coal of the Little Missouri valley will be practically of no commercial value. All of it lies at a great distance from the railroad, in a deep valley, to most points of which no wagon roads will be able to penetrat. The hills hemming in the stream are from 300 to 500 feet high. If the valley becomes settled to its full capacity, the production of stock, farm produce, coal and clays may make it worth while to build a railroad down through the valley. The possibilities for stock raising in this portion of the Little Missouri valley are certainly great, for, with the surety of winter feed, which irrigation would provide, much larger parts of the uplands could be used without overgrazing. The area of the basin north of Medora is about 2,000 square miles, all of which would be tributary to a railroad running from Medora to the Missouri.

The only other way that the coal from this area could be gotten to market at the present time would be by means of flat boats. While the stream is in its average flow this means of transportation would be impossible on account of the shallowness of the water. But floods occur several times during the months of May, June and July, which last several days, or for a time sufficient to float loaded boats from points well up the stream to the deeper waters of the Missouri where tugs might continue the transportation to points further east.

Lignite in Knife River Basin.—Good seams of lignite were found at many points along both Knife river and Spring creek. Many outcrops occur also in the ravines and small creeks remote from the main valleys. Several seams of from two to four feet in thickness were seen cropping at many points above and below Hazen. The following are the localities where coal was especially observed. At many intervening points similar outcrops would also be found if looked for.

1. At Mrs. Wiege's: Township 144, Range 89, Section 9, has a good seam of coal three to four feet thick. A spring runs from the coal.
2. Mr. Hind's: Township 144, Range 88, Section 8, is reported to have a seam of coal ten feet thick.
3. Four miles west of Wiege's and one mile from the creek several small openings have been made, which show coal three to four feet thick.



Coal outcrop south of Mikkleson. The four seams aggregate sixteen feet in thickness

4. Five miles west of Wiege's, at the creek crossing, there is a five foot seam of coal thirty feet above the creek, and covered, over a large area, by only twenty feet of alluvium and clay. Considerable lignite has burned out at this horizon.

5. Vicinity of Halliday: (a) Township 145, Range 91, Section 19. Here several seams of coal outcrop at different levels. Below Mr. Olafson's house, on the creek, there are two seams of three to four feet in thickness. The outcrops extend up and down the stream for some distance.

(b) A coal seam five feet in thickness is reported from a point five miles below Mr. Olafson's at the ranch of Stewart and McBain.

(c) At Sam Juel's house, Township 145, Range 92, Section 4, a large peat bog has accumulated above the coal seam, and in the bog are some very large springs. Mr. Juel uses these springs to irrigate his garden.

(d) A mile and a half west of Sam Juel's house there are several good coal outcrops.

(e) Mr. Engbrettson, Township 146, Range 92, Section 25, reports coal at his ranch.

(f) At Anderson's ranch, six miles north of Halliday, there is a seam of coal from which a large spring issues. Mr. Anderson uses this spring to irrigate a garden.

(g) Two miles southwest of Halliday, on the south side of the creek, there are two outcrops of lignite three to five feet thick, over one of which there is little covering.

6. Paulson's ranch, six miles west of Halliday's, contains a very heavy seam of coal which outcrops in two places where solid coal rises about sixteen feet above the bottom of the creek. (See Plate XXIV.) This coal seam extends several miles west of Paulson's as indicated by the burned clay along the margin of the creek valley.

(7) Vicinity of Fayette: In the valley of the Little Knife west of Fayette, coal outcrops in several places. Good springs issue at the level of the coal. No large seams were seen here. At Fayette there is a seam three to four feet thick. Little coal was seen in the Knife valley west of Fayette, but near the head of one of its branches, Township 144, Range 99, Section 34, northwest of Brannen's sheep ranch a seam of four to five feet in thickness outcrops for two rods on the creek.

8. Farmers valley: Outcrops of lignite were observed in the valley northwest of Richardton, and near the head of Deep creek. The seam was not over four feet in thickness.

9. Knife river: Outcrops along the valley of this stream above the mouth of Spring creek are numerous, the following being the most important.

(a) At Rockspring two good seams of lignite outcrop for several rods along the creek, and there is a similar outcrop three miles above Rockspring.

(b) Paulson's ranch, Township 142, Range 93, Section 12: Here a seam of five to six feet in thickness outcrops along the river at water level.

(c) Martin Hanson's ranch. Township 142, Range 92, Section 9: A seam five feet thick lies just at water level.

(d) Crowley's ranch. Township 142, Range 90, Section 8: Several outcrops of coal in this vicinity, the seams having a thickness of three to five feet.

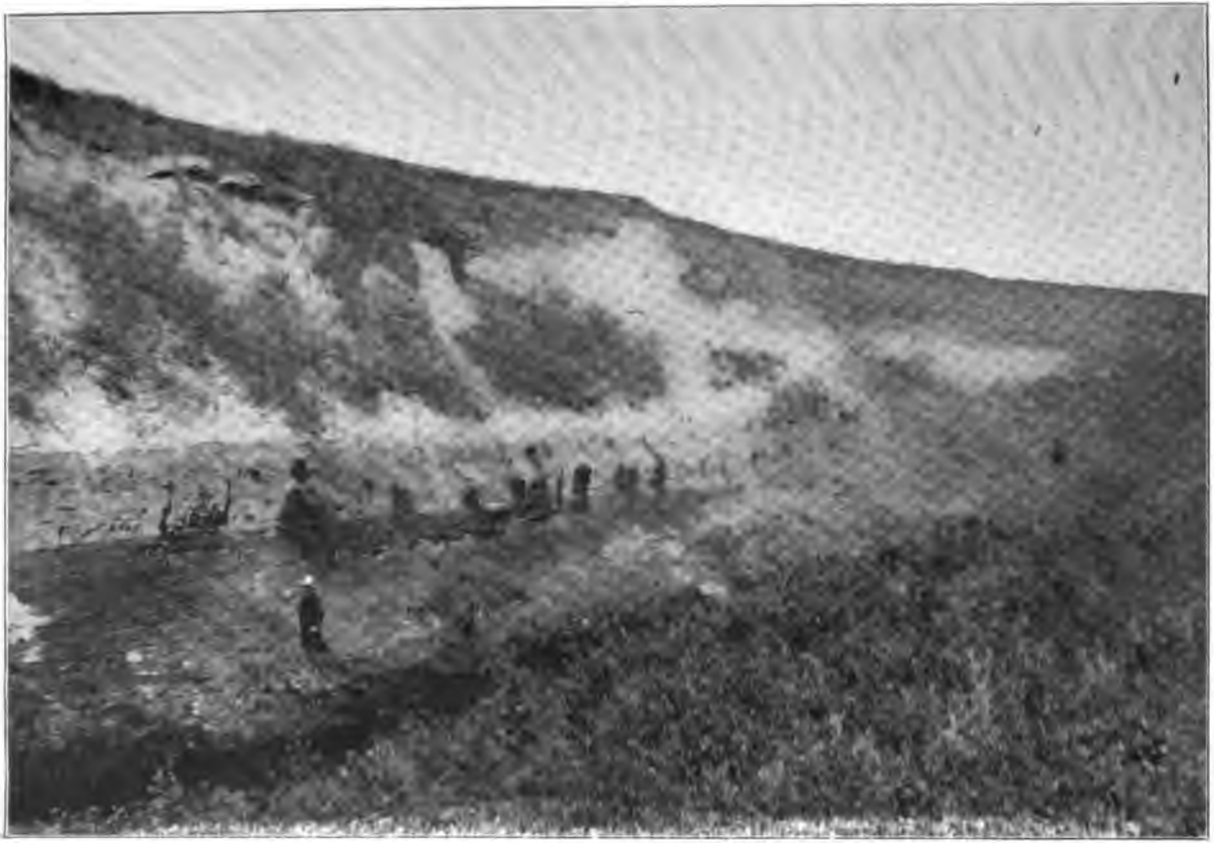
(e) J. Garecht's, five miles below Broncho: Good coal seam reported from this place.

(f) A seam of eight to ten feet was reported from Brady creek four miles south of Hazen.

From the above list of locations it will be seen that while coal is quite generally distributed in the Knife basin, the number of large outcrops is strikingly smaller than along the Little Missouri. This is partly due to a less favorable condition for outcrop, and partly to the drift cover which lies over most of the area. Doubtless much more coal exists here than these outcrops would indicate.

DRIFT PHENOMENA

Margin of the Drift.—The study of the problems of the drift was only incidental to other problems, but the field of work brought the party at several points into contact with the edge of what is called the Kansan drift. The study of the drift is important for the reason that its distribution furnishes an explanation of some of the peculiar features of the region, such as old valleys, springs, the location of the flats, the presence of good soils on the uplands; and, further, it is the cause of the striking contrasts in topography between the little Missouri country and that of Knife river and Spring creek.



Coal seam near Paulson's ranch on Spring creek, ten miles west of Halliday. The seam is sixteen feet thick

The following data furnish the basis for the partial determination of the margin of the drift between Richardton and the boundary line west of the mouth of Bolan creek.

1. Two miles north of the mouth of Beaver creek on the west side of the river, a granite boulder weighing about three pounds was found high up on the face of the bluffs.

2. Two granite boulders weighing sixty and seventy pounds respectively were found in the breaks, west of the river, opposite the mouth of French creek. Also near the same point were two slabs of white dolomite, unlike any rock seen in this vicinity. These were only slightly rounded. To the west of this point up to the crest of the Yellowstone divide for four miles, search was made for more drift, but none was found.

3. Some eight miles north of the point mentioned in (2), just north of the mouth of Bolan creek on the west side of the river, at an elevation of from 200 to 300 feet, much drift material was found. Among the rest may be mentioned the following: large boulders, including white dolomite, hornblende granite, quartzite, and a variety of small materials, all appearing as if they had been dumped here. Also two miles northwest of the mouth of Bolan creek a granite boulder weighing a ton was found.

4. At the head of Squaw creek, just where the valley opens out upon Cherry flats in the ancient valley of the Little Missouri, one and a half miles northwest of the X ranch, much drift was seen. Thirty granite and gneissoid boulders were found in walking over a half mile of the flat. Also there were a number of low, rounded hills on the floor of the valley, gravel covered, and having several granite boulders on their slopes.

Gravel and boulders were reported to be scattered along Cherry valley and the valley of Redwing creek between the head of Squaw creek and Bolan creek.

5. No unquestioned drift was found along the river below Squaw creek until the southwestern corner of the Indian Reservation was reached some ten or twelve miles below the mouth of Cherry creek. From this point on down the Missouri, there was a large quantity of both coarse and fine material. Near the corner of the reservation much coarse gravel appeared in the banks of the stream; and many boulders, so numerous as to make boating in the shallow water difficult, were encountered just below the mouth of Jim creek.

6. About two miles below the old Manning ranch, and fifteen miles east of Oakdale, many large red granite boulders were found, both in the ravines, and on the upland flats, but no fine material was associated with them.

7. Vicinity of the Kildeer mountains. No drift material was found on the west side of the Kildeer mountains, though the entire circuit of the mountains was made by one of the party. Nevertheless the slopes on both the east and west sides of the mountains suggest modification by ice or water action, and small particles of sand and schistose material, found on the tops of the highest buttes on the west side of the mountains, cause one to suspect that ice lay nearby at sufficient elevation to furnish extra marginal drift. Just east of the mountains a dozen granite boulders were found, some of them of great size, together with a large number of a peculiarly hard, flinty quartzites, which were furnished by the area nearby.

From Oakdale eastward the drift increases in quantity, and all the hills are modified in form and reduced in elevation by the action of the ice.

Twelve miles south of the Kildeers a small granite boulder was found on the top of a well rounded hill, and at a point fourteen miles southwest, two limestone boulders similar in character to the limestone that caps the Kildeers

8. At Fayette postoffice many boulders, both of granite and hard quartzite, are found in the gravel terraces, that were observed extending to the east a distance of eight miles. Here Knife river has cut its channel down fifty-five feet below the top of the terrace that carries the boulders. Along this terrace, in a drive of five miles, we found forty granite boulders, besides thousands of angular boulders of peculiar bluish quartzite of fine texture and extreme, flinty hardness.

No drift material was found west of Fayette until the party reached the head of Knife river near Brannen's sheep ranch, where one large gneissoid boulder was found in the valley about forty feet above the stream level.

The rounded forms of the hills, lying far to the west of the road from Oakdale to Fayette, suggest modification by drift, but there was no time to investigate the matter.

9. The next indications of drift were seen at Dickinson Here, just a mile northwest of the city, by the side of the X trail, a granite boulder was found at an elevation of 250 feet

above the river. Other boulders of granite lay along the railroad track, probably dumped there for construction purposes. Again at the clay pits of the Dickinson Fire and Pressed Brick Company a small granite boulder of thirty pounds weight was found lying on the terrace by the river, along with much gravel that covers the surface of the terraces. This material may have been brought in here by floating ice when the stream was blocked below, in the vivinity of Gladstone, by the lobe of the glacier which reached that vicinity. Similar gravels cover the surface of the terraces along Green river near the road from Dickinson to Gladstone. They consist largely of flints, but contain a few pebbles of igneous rock.

10. Gladstone. Here numerous evidences of drift were found. The area examined extends for three miles southwest of Gladstone, is circular in form, and rather well defined, with a topography sharply contrasted to the more rugged hills to the north and south. Several large pink granite boulders were found in the area, some along the river, and others two hundred feet above. On the west side of the area there is a railroad gravel pit, in which were found, gathered into a pile, twenty-eight boulders, presumably worked out of the gravel. The surface of this area of five or six square miles is rolling, and on the west drops off suddenly to broad flats, where, as reported by Mr. Cryne, no gravel is found.

11. From Gladstone eastward the country rises gradually toward Taylor and Richardton, presenting a rolling surface much flatter than the area west of Gladstone. Just how this area merges with the valley of Heart river south of Knowlton was not ascertained; but to the north of Knowlton the rolling land breaks away into a flat that extends toward the north until it terminates somewhat abruptly in the bluff that overlooks Farmers valley.

Several boulders were noticed in this flat lying along the railroad. It seems not improbable that a lobe of the ice extended along the line of this flat to Gladstone on the west.

12. Boulders were found at Taylor and at Richardton. At the latter place several granite boulders were seen built into a stone fence, and also in the foundation of the grain elevator by the railroad track.

13. Farmers Valley. This valley, lying along the escarpment mentioned in (10), extends from Hebron to the mouth of

Deep creek. It was followed from Richardton to its western extremity. Boulders were found throughout this entire distance lying on the low hills of the valley. Just northwest of Taylor the escarpment retreats to the south for several miles, giving place to a rounded hill of about one-half the height of the escarpment. These hills correspond in height and form to the hills and slopes bounding the north side of the valley. The escarpment extends ten or twelve miles northwest of Taylor and north of Green river, until it merges with the higher and rougher land south of the mouth of Crooked creek. Drift was found on the north side of this escarpment, but not on the south, except at Gladstone and Dickinson, and it seems probable that the drift at these places may be explained by supposing that a lobe of the ice sheet advanced over the escarpment west of Taylor, then moved as far as Gladstone. Here it blocked the streams, thus making it possible for floating ice to carry the gravel and few boulders as far west as Dickinson.

On the basis of the observations above stated we have drawn a boundary of the drift on the map, tentatively, however. This was not the primary work of the party, and the data presented above are given to facilitate the study of those who may take the matter up in detail.

Extra Marginal Drift.—Gravel was found as a veneer on most of the bench land at an elevation of more than two hundred and fifty feet above the Little Missouri, as far south as Medora. At several points between Medora and the mouth of Beaver creek these gravels were found to a depth of two or three feet. This material consists of cherts largely, some of which is shown by fossils to be of Mississippian age, and its source not nearer than the Rocky mountains. Among the cherts are pebbles of quartz prophyry, quartz feldspar rock, diabase, flints, silicified wood, and quartzites. The level uplands over a wide area about the mouth of Beaver creek, are covered with sands that seem to have been assorted, since the grain is coarser than that of sand found in the Laramie clays, and of far more porous texture than the ordinary upland surface where such material is not present. The unusually smooth outlines of the upland flats between Mikkleson and the mouth of Bolan creek leads one to suggest as an hypothesis for the origin of part of the gravels, sands, and smooth uplands, that the Little Missouri was dammed near the mouth of Bolan creek by the Kansan ice sheet; as the result of this a large lake was formed in the valley above that would allow ice to distribute material over the bed of the lake to the south. Most of the coarse material, however, probably came from the head of the river in the foot hills of the Rockies, gradually rolled and pushed along to its present position by the current of the stream.

It seems not unlikely, moreover, that the Little Missouri was diverted by the same ice sheet from its former course to the Missouri along the old valley that extends between Bolan creek and the mouth of Tobacco Garden creek, and made to follow instead, the irregular course along the edge of the ice to the north and west of the Kildeers, guided perhaps by the presence of some smaller stream valley already existing in the region.

Farmers Valley.—It seems probable that the edge of the older ice sheet extended along the south slopes of this valley from a point eight to ten miles southwest of Rock Spring, east as far as Richardton, and possibly to Hebron, before it turned south toward the Heart river. The topography along this line, both within and beyond the margin of the ice, shows that the ice did not lie at any great depth over the country. South of Rock Spring there are island-like groups of rough, driftless uplands, rising two hundred feet above surrounding valleys, in which boulders and gravel are abundant. North of Taylor there is an area of several square miles lying in a re-entrant angle of the escarpment itself, and about the same as that of the upland on the opposite side of the valley at the north. The surface of this area has the appearance of having been reformed by ice action. If so the ice filled the valley at least to a depth of two hundred feet, and possibly more than three hundred feet, and advanced on to Gladstone over the escarpment in this vicinity, as before stated. West of this area, for a distance of ten miles or more, the white, bare, clay faces of the escarpment stand out in sharp contrast to the wide valley and its groups of low hills. Deep creek, rising near the escarpment and flowing to the Knife river in the vicinity of Rock Spring, has terraces which in places are gravel covered. Near its head, north of Gunwall's ranch, there are several large sloughs, around which are scattered many boulders. The valley joins with Farmers valley, and this with the valley of Little Knife creek which enters the Knife near Shaffner's ranch, and thus the three valleys form a ring-like depression with the Knife valley as a base.

The explanation of this series of connecting valleys is not easy. It seems possible that the old preglacial valleys of the Little Knife and Deep creek headed near each other in the vicinity of Taylor. Then, during the advance of the ice, the upper waters of the Knife must have turned south for a time, probably through Deep creek valley, so that they would have cut down the divide between the creek and Little Knife; then, later, the flow from the melting glacial ice must have carried off much more material, and thus increased the size of the valley. The cause of the escarpment may be found to be due to hardness of materials, since there is considerable sandstone in the region between Richardton and Dickinson on the west, as was observed in the buttes along the railroad. If this is the case, the advance of the ice to the heads of the old valleys would simply increase the abruptness of the slope on the south, while it rounded off the hills over which it passed on the north.

Quantity of Drift.—The most striking characteristic of the drift covered area is the slight thickness of the veneer over the greater part of the basin of the Knife river. In many places the only element of the drift that remains is a mass of boulders. Till banks were seen in a few places along the south side of the Knife river. At Paulson's house there is a bank of till sixty feet high, containing boulders and gravelly clay. Such banks occur at other points along the Knife below Paulson's both in the bluffs and ridges in the valley, mainly crowded to the south slopes, however. The horizontal beds of Laramie clay, and the unobscured coal seams in the north banks of the river show that little drift remains there if it was ever deposited; while the drift materials on the south bank represent the stuff that was packed by the ice in the old ravines and angles of the banks of the river as it moved up the slopes toward the divide on the south.

A similar distribution of drift prevails along Spring creek. But the thickness of the drift increases toward the north and a depth of several feet covers the hills over considerable areas north of Halliday. Between Halliday and Hans creek the drift becomes abundant enough to have been left in the form of low, rounded hills of a moraine type, between which sloughs and potholes once existed, now mostly drained. East of Halliday there is almost a continuous covering of drift; but two miles west the veneer becomes thin and largely disappears as one passes up Spring creek toward the Kildeer mountains, little remaining to mark the former presence of ice except the boulders, rounded hills, and reduced slopes.

The quantity of drift when compared with that of the great moraine north of the Missouri, seems very small. It also seems entirely too little to correspond with the great modification of slopes and reduction in elevation that seems to have taken place along the area between the moraine of the Coteau north of Coal Harbor on the Missouri, and the margin of the drift. There is but little material except the boulders that necessarily came from localities far north; probably most of what is now deposited was picked up not far from the Missouri. If the region was as rough previous to the invasion of the ice as its geographic relations at present indicate, the erosion by the ice sheet must have been great. The contrast between the topography of this area and that of the Little Missouri region has already been mentioned, and the roughness of valleys of the streams of the driftless area southwest of the Northern Pacific railroad lead one to suppose that an equally rough area was found here in preglacial days. Further, the presence in a few places in the area of patches of badland brakes, as along the north divide of the Knife river, suggests that bad lands covered a considerable portion of the area. If such rough hills have been degraded, and the sharp bluffs along the streams not only rounded off, but reduced by many tens of feet in elevation, we may well ask what has become of the material.

In attempting a solution of the problem above introduced, several considerations more or less remote from the drift itself are in order. The points to be considered are the following:

1. Climate of the ice age. 2. Direction of the ice advance with reference to that of the streams of the area. 3. Time during which the ice was advancing and retreating. 4. Condition of the area with respect to erosion previous to the ice advance. 5. The nature of the materials both of the area and those brought by the ice. 6. The effect of the ice upon the materials of the area transgressed by it.

1. Climate. The prevailing winds were probably the same during the Kansan time as now. The Gulf stream furnished the moisture to the air which carried northward would reach its dew point rather suddenly on coming in contact with the margin of the ice. Such a sudden cooling would lead to a concentration of rainfall in this region. The seasonal distribution of rainfall

would be about the same as at present, since the controlling factors are the same now as then; this would bring the larger amount of rain during the early summer, which combined with the melting of the ice by the summer heat, would effect a rapid degradation of the clays south of the margin of the ice. This action would continue through the long period while the ice was advancing and retreating through a distance of seventy or eighty miles.

2. Relation of margin of ice to stream direction. Assuming the direction of the ice movement to have been toward the south, the line of advance would form a very acute angle with the preglacial direction of flow of the streams, the result being that they were gradually forced to shift toward the south until their valleys became filled with ice. Then they would overflow at the lowest level. Large lakes would be formed at the head of the stream; and even now such basins actually exist in the vicinity of the Kildeer mountains, along the upper course of Knife river, and Spring creek. The Missouri was gradually forced out of its channel, and the flood of waters from the west must have found its way over this area somewhere, if relative elevations of the time were such as exist today. It seems quite probable that the waters of the Missouri found their way to the southeast by one or all of the old valleys that lie north of the railroad, and possibly by the Heart river. Goodman and Farmers valleys are all much too large to have been made by the streams that now occupy them, and their width may be explained by such an assumption as the above. Such a movement of water would have greatly degraded the soft materials of the area even before the advance of the ice.

3. If the time during which the ice was advancing was as long as the rate of ice movement of modern glaciers would suggest, then the period during which erosion was going on by the agents suggested in (2) was long enough to bring about considerable reduction of the elevation of the area; and to remove much material, as well as to lessen the roughness of the surface. This overflow sought the lower levels of the divides, leaving some of the higher portions untouched. These remain today much as of old. As the melting was in excess of the ice formed during the winters, the quantity of water flowing away in a given length of time was greater than while the ice was advancing, and the erosion was even more rapid for that length of time. The flow from the ice, plus the flow from the streams which gradually

shifted northward back to their old channels, all tended to the degradation of the area.

4. Condition of the area at the time of the ice advance. Even after deducting the effect of leveling by the shifting extra marginal flow of water, there must have remained many small valleys in all parts of the area which became receptacles for part of the material crowded forward beneath the ice. Thus we should expect to find these old valleys entirely obliterated by drift filling, and it is believed that detailed work over the area would discover many such. This amount could be added to the quantity carried off by surface erosion in the attempt to account for the discrepancy between the degredation and the amount of drift present in the area.

5. It is to the nature of the materials that we must turn to find an adequate cause for lack of quantity in the drift. Throughout the area there is no material, aside from coal, that is harder than soft sandstone, and of this little except in the form of concretions, which would in most cases offer less resistance to erosion than tough clay. Much of the clay is sandy, and all of the materials are so fine grained as to be readily carried off by moderate currents of water. The advance of the ice would tend to loosen large masses of the material by pressure, so fitting them for rapid transportation by the streams.

With respect to material from more distant regions, it is probable that there was no great quantity. Of this the boulders frozen into the ice would constitute the larger part, and the remainder would have been gathered largely from adjacent clay uplands on the north, materials as easily handled as those of the area itself.

6. And finally it is necessary to consider what would be the effect of the movement of a great mass of ice several hundred feet thick over an area with the characteristic erosion features and materials of this one. It has been shown that in its movement over surfaces of varying roughness, the ice has little effect on the smoother reaches, while it either removes entirely or greatly reduces the elevation of such features of topography as offer resistance to horizontal movement. From this manner of action, then, the abrupt slopes of the sharp erosion hills of this area must have suffered most as the ice drag passed by. The north bluffs of the east-west stream valleys must have been unable to withstand the pressure due to the weight and crushing

motion of the ice from the north, and born down by the stream, they became easy prey for the water moving along the margin of the ice. Again as the ice pushed its way across the river valley and up the opposite bank, this would likewise give way to erosion by water and the degrading action of the ice, so that a more gentle slope would remain. Such seems to have been the action along Spring creek, and to almost an equal amount on Knife river. Long, gradual slopes today extend from the crests of the divides down to the middle of the channels. Few parts of the region remain unmodified, though some rather rough uplands, with steep and almost impassable bluffs, remain along the crest of the divide of Knife river in the vicinity of Broncho, and farther west near Fayette. The highest of these hills, 300 feet above the river level, are covered with boulders, showing that the ice extended over them. The material carried by the ice, including the boulders, was scattered over the area, the amount carried becoming less and less as the ice grew thinner toward the south. Thousands of boulders are scattered in drifts along the slopes of both streams, many of which lie conspicuous on the hillsides, the finer material deposited with them having been carried away by the streams. In some places more or less gravel has been left with the boulders, as was observed near Rock Spring and along Deep creek. The time since the ice left the area has not been long enough to permit the streams to cut new channels back into the hills of greatly reduced slopes. Neither do the hills and valleys seem to have been much affected by erosion since the ice age. This is due to several causes. The drift veneer forms a loose, porous layer over the surface that takes up much of the rainfall, and either allows it to seep gradually down to the impervious clay to issue as springs, or by the very act of holding the moisture for some time permits much of it to pass away by evaporation. Again the runoff is somewhat delayed by the reduction of slopes, and consequently the erosive action goes on but slowly. Though the actual size of the Knife basin is about one-third that of the Little Missouri the runoff according to measurements in the last season, is but one-seventh to one-tenth that of the stream which flows much of the way through bad lands of steep slope. Again, vegetation has taken a much firmer hold on the long, gentle slopes so that erosion has been impeded on this account.

The striking changes wrought in the topography by the causes outlined above may be seen by one in looking from the Kildeer mountains, a point from which he can contrast the unmodified bad lands with the greatly reduced relief of the area of the Knife and Spring creek valleys.

TOPOGRAPHIC FEATURES AND GEOLOGICAL FORMATIONS OF NORTH DAKOTA

by

A. G. LEONARD

TOPOGRAPHY

Considered in relation to elevation above sea level the land surface included within the bounds of the state may be regarded as formed of three plains rising one above another. The lowest of these is the broad Red River valley with an elevation of from 800 to 1,000 feet. This is bordered on the west by a higher plain rising from 1,200 to 1,600 feet above the sea, while still farther west and occupying nearly one-half of the state is the elevated highland of the Coteau du Missouri with a surface which rises 1,800 to 2,700 feet and over above sea level. The state thus presents a considerable range of relief, the lowest point, which is in the northeastern corner, being 789 feet above the sea, while the highest yet determined, the summit of Sentinel Butte, is over 3,100 feet.

The remarkably level plain known as the Red River valley stretches along the eastern border of the state and extends from thirty to forty miles west of the river. Near the southern end, at Wahpeton, the valley has an elevation of 965 feet, at Fargo it is 905 feet, at Grand Forks 830 feet and at Pembina, near the Canadian line, 789 feet above sea level, the slope toward the north being about one foot to the mile. It is bounded on either side by higher land rising from 300 to 700 feet above the plain.

Separate names have been applied to different parts of the elevated region bordering the Red River valley on the west and extending far beyond the boundaries of the state, with a length of about 800 miles. The Manitoba escarpment is the eastern edge of the northern portion of this highland, lying mostly in the province of the same name. The slope forming this conspicuous escarpment rises abruptly 300 to 500 feet and over from the lower to the upper plain; the latter stretching far away to the westward. The Pembina Mountains constitute part of this line of prominent wooded bluffs, which extends south into Walsh county, where it gradually fades out. Southward from here almost to the southern boundary of the state the slope leading to the westward stretching highland is gentle and inconspicuous, but the ascent is still 400 to 500 feet. In southeastern Sargent county and extending into South Dakota is the high plateau-like region widely known as the Coteau des Prairies and forming the southern extension of this same elevated plain. In North Dakota the width of the latter varies from about seventy-five miles at the south to over 200 miles near the Canadian line. On the west this plain is interrupted by a second abrupt slope leading up to the high upland which forms the Coteau du Missouri. Its general surface lies at an elevation of from 500 to 700 feet above the adjoining country to the east, and rises gradually west of the Missouri to a height of nearly 2,800 feet above the sea. In Williams and Ward counties the elevation of the upland is from 2,250 to about 2,400 feet. The eastern edge of the Coteau du Missouri has a general northwest-southeast course across the state, extending diagonally through Ward, northeastern McLean and southwestern Wells counties, then with a more southerly trend crossing western Stutsman, LaMoure and Dickey counties from twenty to thirty miles west of the James river. The Soo railroad from Carrington to Portal, on the international boundary, runs parallel to the edge of the Coteau, and from ten to twenty miles east of it. As previously stated, the plateau of the Coteau du Missouri occupies nearly one-half of the state. On account of its abruptness the slope marking the eastern edge of this plateau is cut at frequent intervals by ravines and gulches. These are perhaps best developed in Ward county, where there are no less than fifty within a distance of seventy miles.

The topography of North Dakota presents greater variety than one might at first imagine. There are the level lacustrine plains of the Red River valley and of the Mouse river region in Bottineau and McHenry counties; the wide stretching, gently rolling to rough drift plain with its innumerable lakes, its comparatively few rivers and imperfect drainage, occupying nearly two-thirds of the state; and the highland area west of the Missouri largely free from drift, with its many buttes, its picturesque bad lands and characteristic erosion topography. These three types of land surface differ widely in origin and present many points of contrast. The vast drift plain, which includes a large portion of the Coteau du Missouri, owes its peculiar features to the deposits made by the continental glacier—its topography is due to the accumulation and deposition of drift. This area is in marked contrast to the erosional topography of the driftless portion

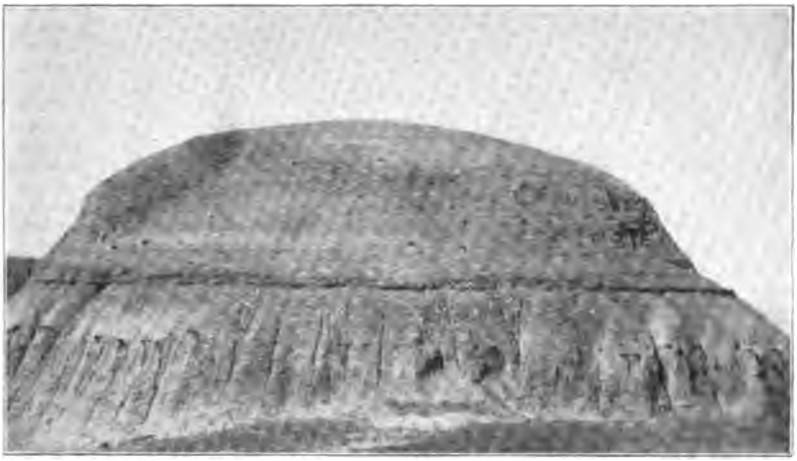


Fig. 1. A dome shaped butte near the base of Sentinel Butte, showing many concretions projecting from the clay slope

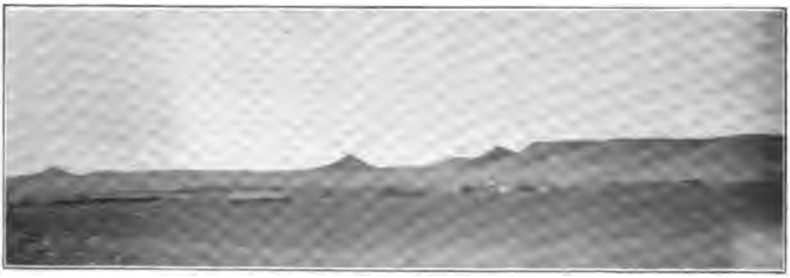


Fig. 2. Several low buttes near the station of Sentinel Butte

beyond the Missouri, and to the flat, featureless plain on the east.

The continental ice sheet has been by far the most important factor in moulding the surface features of the state. Its effects are everywhere apparent and unmistakable. Before its advent the area under discussion was probably much more uneven than at present, being an old land surface which had been roughened by the erosion of streams. The continental glacier modified all this and tended to level up the region by wearing down the hills and ridges and filling the valleys with debris. Upon its retreat there was left the heavy mantle of drift, which conceals from view the preglacial surface. It is this drift which forms the rolling, and in places rough plain stretching westward from the Red River valley clear to the Montana line north of the Missouri, and extending fifty miles or more south and west of that river. Wherever the edge of the ice remained stationary for a time a terminal moraine was heaped up.

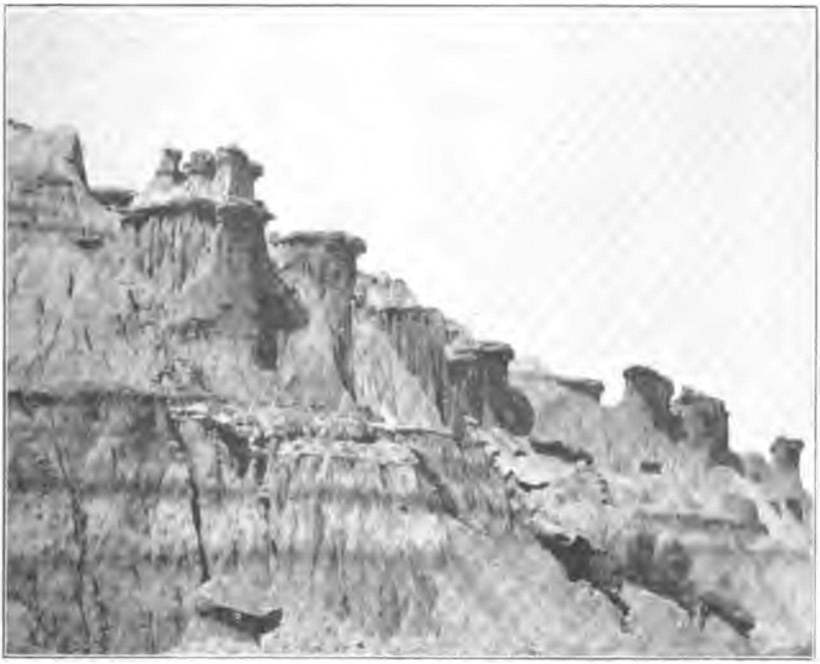
Eleven such moraines occur in the eastern half of the state and their presence adds much to the roughness of the surface. The Altamont moraine, which is the first or outer one, lying farthest to the west, is described on a succeeding page in connection with the drift. It has a northwest-southeast course across the state, and in Ward county lies along the eastern edge of the Coteau du Missouri. Each moraine consists of a single ridge of drift or belt of ridges and hills varying from a mile or two to fifteen and twenty miles in width. These hilly, morainic belts are often conspicuous topographic features and can be seen from a distance of many miles. The individual hills sometimes rise 100 to 200 feet above the general level of the country, or again they are low and gentle elevations. Many of the hollows and depressions among the hills are occupied by lakes and marshes, which are characteristic of terminal moraines. The lakes are not confined to the morainic areas, however, but are numerous all over the wide-stretching drift plain. They dot the surface by the score and hundred and add beauty and picturesqueness to the landscape. The largest is Devils Lake, which owes its existence to the partial filling up of an old river valley and its tributaries with glacial drift.

The small number of rivers is another noticeable feature of this plain. Aside from the Missouri near its western border, the Mouse, James, and Sheyenne are the only streams of any importance and even these have few tributaries. There are entire counties without a single river. This scarcity of streams and abundance of lakes indicates a young land surface on which the drainage channels have not yet had time to become thoroughly established and the lakes have not been drained or filled up. Lakes are but ephemeral features at most, since they are either sooner or later drained by the lowering of their outlets or are filled with sediment from inflowing rivers.

Quite a different type of topography is presented by the region lying west of the Missouri, where the surface features are the result largely of erosion. They are due to the action of rain and running water, and not to the accumulation and deposition of glacial debris, which resulted in the formation of the rolling drift plain with its own peculiar topography. In the unglaciated region there are almost no lakes and the area is well supplied with streams which have cut valleys from 100 to 400 feet deep, ramifying in all directions. The large number of buttes rising above the general level of the country is a conspicuous feature here. These are perhaps best seen in the vicinity of the station of Sentinel Butte, where the plain is dotted with many symmetrical, conical shaped hills. Most of the low buttes have an elevation of about 150 feet above the general surface and are seen to be capped with masses of red, burnt clay. The latter was formed by the burning of a coal seam, apparently the eight-foot seam occurring at about the same elevation in Sentinel Butte. The stratum of fused clay has protected the tops of the buttes and given them their uniform height. There are also the high buttes, rising 400 feet and more above the plain at their base, usually flat topped and capped with sandstone. Sentinel, Bullion, Square and Camels Hump buttes may be cited as examples.

By far the most interesting feature of the unglaciated region and in fact the most interesting topographic feature in North Dakota is the famous bad lands. The true bad lands, that is, the very rough areas that are difficult to travel through, are confined to the vicinity of the streams. Back from these five or six miles the land is a rolling plain and is not "bad" in the sense probably meant by the old French term *mauvaises terres* originally applied to the region with reference to its being a land bad for the traveler.

The bad lands are typically developed along the Little Missouri and Medora is located in their midst. The soft Cretaceous



View showing the effect of rain erosion on the Laramie beds. The clay pillars are capped and protected by hard, silicious concretions. Near Williston

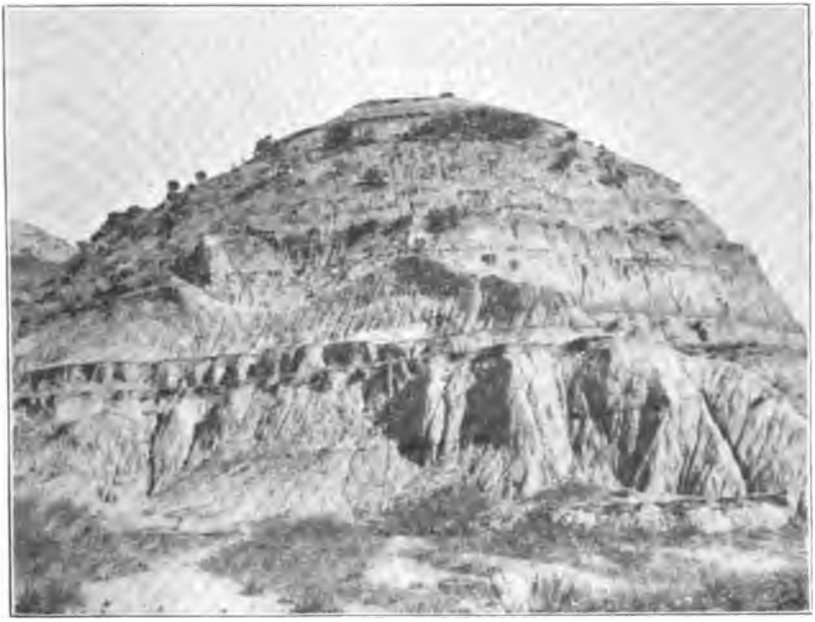
clays and sands described on succeeding pages have been carved by running water into a multitude of steep-sided hills, isolated buttes and an endless variety of fantastic forms. The change is abrupt from the gently rolling plain to the strip of bad lands bordering the river and forming a belt ten to twenty miles wide, within which the effects of erosion are so plainly seen on every hand. This erosion is greatly facilitated by the sparseness of the vegetation, the slopes being almost bare of verdure, and by the softness of the rocks. Though the region is one in which the rainfall is light, every shower is highly effective in washing away the unconsolidated sands and clays. The slopes, the sides of every hill and butte, bear the marks of the last shower. They are grooved with countless tiny channels formed by the little rivulets of water which poured down the slopes. Each rivulet gathered up its load of detritus and carried it on to the main stream. The river has its numerous tributaries and these in turn have their branches which are ever working back into the land. And thus what was formerly a comparatively level plain, similar to that about Dickinson, is now carved into the weird and picturesque bad land topography which is described and figured in all text books of geology.

Beauty and variety is added to the landscape by the diversity of color. The colors are arranged in broad bands along the faces of the bluffs—gray, yellow, black and red of every shade and tint, together with browns and pinks. The banded and many hued bluffs, buttes, domes and pinnacles are a characteristic feature of the bad lands and increase their attractiveness from a scenic point of view.

Turtle Mountains.—This name is applied to the high, rough, plateau-like area occupying a portion of northern Bottineau and Rolette counties and extending across the boundary into Canada. The mountains have a length of over forty miles, a width of about twenty-five miles, and rising as they do 400 to 600 feet above the level plain at their base they are seen for a distance of many miles. This highland is to be considered an outlier or remnant of the Coteau du Missouri, of which it undoubtedly at one time formed a part. The Laramie clays and sands which underlie the Coteau formerly extended east as far as the Turtle mountains, if not farther, and by the erosion of the horizontal beds of that formation this portion of the plateau has been left far beyond the escarpment marking the edge of the main plateau. The intervening depression is the level plain formerly covered by Lake Souris but now traversed by the Mouse river as it flows first south and then swings around to the north and recrosses the line into Canada. The Turtle mountains received a heavy deposit of glacial drift, which has a thickness of 100 feet and more and forms no small part of their height. Over a large part of this highland area the topography is distinctly that of a terminal moraine with its numerous, irregular hills and hollows, the latter occupied by lakes and marshes. The most noticeable features of the region are the great number of lakes, among which Fish lake, about twelve miles north of Bottineau, is the best known, and the exceedingly rough, hilly surface, though there are certain portions which are quite level. Some of the higher points, such as Butte St. Paul, rise 2,300 feet above the sea, and the general elevation of the plateau is from 2,000 to 2,100 feet.

The Turtle mountains are the result of two agencies, water and ice. It was stream erosion which, by carrying away the surrounding strata, first fashioned them from the horizontal Cretacious beds and it was the continental glacier which passed over and modified them, leaving behind the heavy mantle of drift. The peculiar heaped up, hill and hollow topography of this glacial drift gives the mountains their present aspect.

Pembina Mountains.—These are formed by the eastern edge of the highland which borders the Red River valley on the west. In Walsh, Pembina and Cavalier counties the ascent from the lower to the upper plain is abrupt, being from 300 to 400 feet within one or two miles and less, and is marked by a line of wooded bluffs which may be seen from a great distance across the valley. It is this conspicuous escarpment, formed by the outcropping edges of the westward extending horizontal beds of the Cretacious formations, which has received the name of the Pembina mountains. They are the southern continuation of the Manitoba escarpment of the Canadian geologists, which extends north several hundreds of miles along the western border of the Red River valley. The streams tributary to the Red River of the North have eroded their valleys back into the highland and in this part of their course they flow in deep, picturesque gorges. The Pembina river emerges from the escarpment through a steep sided valley 300 to 400 feet deep.



View showing the effect of rain erosion on the Laramie clays and sands. The water channels cut in the slope are clearly shown. Near Williston

River Valleys.—Among the prominent topographic features of the state the river valleys deserve mention. The Missouri flows in a valley from one to several miles in width and 200 to 400 feet deep. It has a broad flood plain, above which lie one or more terraces or flats, and back of these rise the bluffs. In the latter the Laramie beds are often exposed, though the slopes are for the most part gentle, drift covered, and clothed with vegetation. At the big bend near Coal Harbor the river swings against the bluffs along the east side of the valley and these rise abruptly from near the water's edge, while on the opposite side of the valley there is a broad flood plain and the level of the upland is reached by a gradual ascent. Such a difference in the bluffs on opposite sides is common.

The tributaries of the Missouri from the west, the Little Missouri, Cannon Ball, Heart and Knife, have all cut their valleys from 100 to 400 feet below the level of the upland plain and have more or less well developed flood plains a mile or more in width, bordered by terraces.

The James and Sheyenne rivers have eroded their valleys in the drift plain to a depth of 125 to 150 feet and more. Below Jamestown the James river flows in a flat-bottomed valley one-half to a mile wide and with rather abruptly sloping sides.

The valley of the Des Lacs river contains the long, narrow lakes known as the Lower, Middle and Upper Des Lacs, the latter being about twenty-five miles long.

The following list of elevations, taken from Gannett's Dictionary of Altitudes*, shows the altitude above sea level of many railroad stations in North Dakota:

ELEVATION OF RAILROAD STATIONS.

LOCALITY	ELEVATION
Almont	1,920
Alta	1,427
Anamoose	1,620
Antelope	2,411
Arvilla	1,017
Ashley	2,001
Balfour	1,613
Bartlett	1,529
Bathgate	821
Beach	2,756

Bulletin No. 160, U. S. Geol. Surv.

LOCALITY	ELEVATION
Bear Butte, Turtle Mountain	2,200
Belfield	2,579
Belle Plain	1,270
Berlin	1,470
Berthold	2,082
Berwick	1,482
Bismarck	1,670
Bismarck, Missouri river, low water	1,618
Bismarck, Missouri river, high water	1,638
Bottineau	1,638
Bowbells	1,958
Boynton	1,495
Buffalo	1,202
Buford	1,944
Buford, Fort, Yellowstone river, low water	1,855
Buford, Fort, Yellowstone river, high water	1,875
Burlington	1,590
Butte St. Paul, Turtle Mountain	2,300
Cando	1,488
Canfield	905
Carpio	1,696
Carrington	1,579
Casselton	934
Cathay	1,585
Churchs Ferry	1,458
Cleveland	1,842
Colgate	1,177
Coteau du Missouri	1,800
Crystal Springs	1,792
Cuba	1,352
Curlew	1,956
Dalrymple	922
Dawson	1,748
Des Lacs	1,897
Delamere	1,066
Delta	2,258
Denbigh	1,485
Devils Lake	1,434
Devils Lake station	1,464
Dickinson	2,405
Donnybrook	1,760
Drayton	798
Driscoll	1,871
Eagles Nest	2,098
Edgeley	1,568
Eland	2,436
Eldridge	1,541
Ellendale	1,449

LOCALITY	ELEVATION
Emerado	898
Fairmount	983
Fargo	903
Fessenden	1,610
Fingal	1,277
Forest River	862
Forman	1,249
Fort Yates	1,670
Foxholm	1,657
Fryburg	2,768
Gassman	1,682
Geneva	1,835
Gladstone	2 348
Glenullin	2,070
Grafton	827
Grand Forks	830
Grand Harbor	1,454
Granville	1,503
Haggart	905
Hankinson	1,068
Harvey	1,596
Havana	1,294
Hebron	2,158
Hillsboro	901
Hobart	1,419
Inkster	1,036
Jamestown	1,408
Kenmare	1,799
Kensal	1.541
Knife River	2,188
Knox	1,605
Kulm	1,966
Kurtz	2,025
Lakota	1,514
La Moure	1,307
Langdon	1,610
Larimore	1.134
Leeds	1,514
Leola	1,587
Lisbon	1,091
Little Missouri station	2,266
Lone Tree	1,995
Lucca	1,199
McCanna	1,140
McKenzie	1,698
Magnolia	1,077
Mandan	1,646
Manfred	1,605

LOCALITY	ELEVATION
Manitou	2,275
Mapleton	907
Matteson	1,380
Mayville	978
Medina	1,794
Medora	2,267
Menoken	1,720
Merricourt	1,644
Michigan City	1,517
Milton	1,586
Minot	1,557
Minto	820
Napoleon	1,955
Neche	831
New Salem	2,163
Niagara	1,440
Northwood	1,119
Norwich	1,526
Oakes	1,320
Ojata	858
Oriska	1,270
Park River Junction	1,133
Park River	998
Pembina	789
Pembina Mountain	1,500
Petersburg	1,519
Pleasant Lake station	1,603
Portal	1,954
Ray	2,271
Richardton	2,466
Rolla	1,818
Ross	2,287
Rugby	1,561
Rugby Junction	1,561
St. John	1,945
St. Thomas	840
Sanborn	1,444
Sandoun	1,074
Sawyer	1,525
Scoria	2,482
Sedalia	2,032
Sentinel Butte	2,709
Sheldon	1,080
Sidney	954
Sims	1,962
South Heart	2,482
Spiritwood	1,479
Spring Brook	2,113

LOCALITY	ELEVATION
Stanley	2,252
Steele	1,859
Sterling	1,867
Stump Lake	1,417
Sully Springs	2,575
Sunnyside	1,658
Sweet Brier station	1,806
Tappen	1,762
Taylor	2,488
Thompson	865
Tioga	2,273
Tower	1,172
Towner	1,475
Turtle Mountain	2,150
University	833
Urbana	1,472
Valley City	1,220
Velva	1,511
Voltaire	1,587
Wahpeton	965
Wheatland	993
Wheelock	2,374
White Earth	2,087
Williston	1,854
Willow City	1,471
Wimbledon	1,486
Windsor	1,840
Wyndmere	1,062
York	1,612

THE GEOLOGICAL FORMATIONS OF NORTH DAKOTA

Of the rock formations which compose the earth's crust but few are found in North Dakota and not all of these appear at the surface. Some are known to occur only from the records of deep wells and are concealed from view by the overlying strata. Before considering these formations somewhat in detail it will be well to review briefly the more important divisions of geological history.

The oldest rocks of the earth, those which are believed to have existed at one time in a state of fusion, belong to the Archean Era. These rocks are mostly crystalline, that is, they are composed of crystals of various minerals which have crystallized out of the original molten magma, and afford almost no evidence of the existence of life at this early period. The granites are examples of these ancient igneous or crystalline rocks, which form the foundation for the more recent beds.

The other great divisions of the earth's history, as recorded in the strata, are based on the life forms they contain. The earliest organisms were of simple structure and the same types existed all over the globe There has been a gradual development of animals and plants by which they have become more highly organized, more complex in structure and more like modern types. Now that this succession of life forms has been made out it furnishes the means of determining the age of the beds forming the earth's crust and the order in which they were laid down. Certain fossils are found only in strata of a certain age, others are restricted to beds of a different age. It is thus possible by means of the organic remains contained in them to determine the succession of the formations and to correlate strata in widely separated areas.

The Paleozoic Era, or the time of most ancient life, was characterized by forms for the most part very unlike those of today; the modern types of animals and plants were almost entirely wanting and the vertebrates were represented only by strange, armored fishes and amphibians. The Paleozoic was followed by the Mesozoic Era or time of middle life, when great numbers of enormous reptiles inhabited the land, the sea, and the air and were the predominating forms. During the last or Cenozoic Era, signifying most recent life, modern animals and plants began to appear and the ancient types became almost extinct.

These three great divisions of geological history are in turn separated into shorter subdivisions or periods, each characterized by its own peculiar life forms. The Paleozoic Era, for example, is divided into the Cambrian, Ordovician, Silurian, Devonian and Carboniferous periods, The Devonian is marked by the culmination of the fishes, which were present in great numbers and of large size, and during the Carboniferous coal-forming plants grew in great abundance and luxurience.

Rocks belonging to all four grand divisions are present in North Dakota, although those of the Archean and Paleozoic are known only from well records. The formations which appear at the surface belong to the Mesozoic and Cenozoic eras and have a wide distribution throughout the state. The geological column of the formations found in North Dakota is shown in the following table.

TABLE OF NORTH DAKOTA GEOLOGICAL FORMATIONS

	FORMATIONS OCCURRING IN NORTH DAKOTA
CENOZOIC ERA:	
Pleistocene Period, represented by	Drift
Tertiary Period, represented by	Marls and limestones of Sentinel Butte.
MESOZOIC ERA:	
Cretaceous Period, represented by	Laramie Fox Hills Pierre Niobrara Benton Dakota
PALEOZOIC ERA:	
Devonian Period, Silurian Period, Cambrian Period, represented by	Shales, limestones and sandstones.
ARCHEAN ERA, represented by	Granites.

Archean.—The crystalline rocks of this era, which are chiefly granites, gneisses and schists, constitute the foundation upon which rest the later sedimentary formations. They have been reached in a number of deep wells in the eastern part of the state and across the line in Minnesota, and they undoubtedly form a part of the great Archean area of Canada and the Lake

Superior region. The granite outcrops in the vicinity of Big Stone lake, not many miles from the southeastern corner of the state. At Moorhead it is struck at a depth of 365 feet and at Grand Fork this ancient rock lies 385 feet below the surface, being covered by beds of clay, sand and gravel, with a thin layer of Silurian limestone immediately overlying it.

Cambrian.—The only evidence of the occurrence of strata of this age within the state is furnished by the record of the well at Grafton. Here the Archean is overlain by 288 feet of shales and sandstone which are believed to belong to the Cambrian.* Beds belonging to the same age are found farther north in Manitoba, south and west of Lake Winnipeg and they are undoubtedly continuous with those encountered in the Grafton well.

Silurian.—Silurian rocks underly a portion of the Red River valley and form quite a wide belt extending along the western shore of Lake Winnipeg and to the northwest. Fragments of Silurian limestone, containing characteristic fossils, are not uncommon in the drift of the northern countries and a boulder in which was a large Orthoceras was found as far south as Sargent county. They have been brought into the state by the continental glacier, probably from outcrops in Canada. In the Grafton well the beds referred to the Lower Silurian have a thickness of 317 feet, including the Galena and Trenton limestones, 137 feet; the Saint Peter sandstone, 93 feet, and the Lower Magnesian shales, 87 feet. In the deep well at Grand Forks, forty miles south, only one foot of Silurian limestone was encountered just above the granite. This may indicate either that the Silurian sea in which the strata were laid down did not extend far to the south or that, after having been deposited, the beds were eroded over this portion of their area, leaving only part of their original thickness. The Silurian formation appears to thicken quite rapidly toward the north, for while at Grafton, as already stated, it is 317 feet thick, sixty miles north at Rosenfield, Canada, it has increased to 892 feet. On the other hand, it thins out toward the west and at Morden, twenty-seven miles from Rosenfield and fifteen miles north of the international boundary, the Silurian is absent, as shown from the well record. The Dakota sandstone rests directly on the Devonian beds.

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* Upham, Mono. U. S. Geol. Surv., No. xxv., p. 77.

Although rocks of the *Devonian* period are, so far as known, absent from North Dakota, they cover a narrow strip of territory lying just west of the Silurian area of Manitoba. At Morden, at a depth of 412 feet, a well penetrated 188 feet of red and gray shales and porous limestone believed to belong to the Devonian. It is not unlikely that these strata extend south some distance across the boundary.

CRETACEOUS

The strata of this period cover almost the entire state, except a narrow strip along the eastern border, and are of great economic importance; they contain thick seams of lignite and a variety of valuable clays, they supply an abundance of artesian water and have furnished the materials composing the rich soils of the region.

The Cretaceous rocks of North Dakota are a part of a larger area which forms a broad belt lying east of the crest of the Rocky Mountains and extending from Texas to the Province of Athabasca in Canada. These strata underlie the greater portion of the great plains region, though they are in small part covered by the later deposits of the Tertiary. The beds of this period are divided into the Upper and Lower Cretaceous, but only the Upper is found in this state.

The Cretaceous rocks of the Upper Missouri were studied as far back as 1854 by Meek and Hayden* who published what is known as the Upper Missouri Section. This has long been recognized as the standard of reference for the Cretaceous deposits of the interior regions and is given below.

UPPER MISSOURI SECTION OF MEEK AND HAYDEN

No. 5. Fox Hills group.
No. 4. Fort Pierre group.
No. 3. Niobrara group.
No. 2. Fort Benton group.
No. 1. Dakota group.

The Laramie formation, which is now included with the Cretaceous, was referred by these investigators to the Tertiary. They named the various subdivisions from the localities where the rocks were well developed. The Dakota sandstone received its name from Dakota City, Nebraska, where it was first studied; the Fort Benton clays from the fort of the same name on the Upper Missouri in Montana; the Niobrara clays and chalk rock from their extensive development along the Niobrara river near its junction with the Missouri; the Fort Pierre clays from Fort Pierre, South Dakota, in the vicinity of which they cover a large area; and the Fox Hills sandstone from the range of hills in South Dakota between the Cheyenne and Moreau rivers, west of the Missouri.

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* Proc. Acad. Nat. Sci. Phila., Vol. 8, 1856, pp. 265-286.

The Upper Missouri section of Meek and Haydən is modified by White in his correlation paper on the Cretaceous* and the following formations are recognized, with their equivalents in the earlier classification.

MEEK AND HAYDEN'S UPPER MISSOURI SECTION

Upper Cretaceous	Laramie formation	...Not recognized as Cretaceous.
	Montana formation..........	Fox Hills group. Fort Pierre group.
	Belly River formation	Not recognized.
	Colorado formation..........	Niobrara group. Fort Benton group.
	Dakota formation	Dakota group.

The Belly river formation is found in Canada but does not occur in North Dakota.

In some large areas the chalky limestones and marls of the Niobrara are not present but are replaced by shales and sandstones. It is then very difficult, in the absence of characteristic fossils, to separate the dark shales of the Fort Benton from those of the Fort Pierre. To overcome this difficulty Clarence King proposed the term Colorado group for the clay members of the Cretaceous, making it include the Fort Benton, Niobrara and Fort Pierre groups of Meek and Hayden. But the Colorado formation, as the term is now commonly employed, is made to include only the Fort Benton and Niobrara, as given above, the Fort Pierre shales being placed in the overlying Montana formation.

The following table shows the Cretaceous formations which are found in North Dakota as they are now classified:

Laramie formation	
Montana formation	Fox Hills Pierre
Colorado formation	Niobrara Benton
Dakota formation.	

DAKOTA FORMATION

At the base of the Upper Cretaceous lies the Dakota sandstone, which is of great economic importance in North and South Dakota as the source of artesian water. This formation does not outcrop anywhere in the state and lies at a considerable depth below the surface. In the eastern counties it has been struck at depths varying from 1,000 feet and less to 1,450 feet. The Devils Lake well reached the sandstone at 1,431 feet and at Jamestown it was encountered at about 1,450 feet, while further south it lies nearer the surface. The water enters the rock where it outcrops along the flanks of the Rocky Mountains and Black Hills, and since the formation dips toward the east it finds its way through the porous sandstone to a great distance from the surface exposures. The beds become saturated with water and serve as a reservoir for the artesian supply.

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* Bull. 82 U. S. Geol. Surv. 1891, p. 163.

The Dakota sandstone, like most of the other formations of the Upper Cretaceous, has a very wide distribution, extending all the way from Texas thorough Kansas, Nebraska, and the Dakotas into Canada and west to the Rocky Mountains. It forms a very persistent and readily recognizable horizon.

In the absence of exposures within the state information concerning the character of this formation is derived partly from descriptions of the rock as found elsewhere and partly from the records of deep wells. The rock is a gray and brown sandstone containing layers of clay or shale. At the base of the formation there is sometimes a conglomerate. The sandstone varies from rock that is quite firm to sand which is barely consolidated and is frequently so soft as to be readily excavated with a pick. Fossil leaves are very abundant in places and the flora of the Dakota sandstone includes no less than 450 species of trees and other plants resembling those of today.

The thickness of the sandstone varies widely at different points but it is seldom more than 500 feet and is commonly less. At Morden, Manitoba, twenty-five miles northwest of Walhalla, the deep well record shows that the Dakota is ninety-two feet thick, formed of sandstone with interbedded shales and resting on Devonian strata. Elsewhere in the same district outcrops of the sandstone and wells penetrating it show that its thickness varies from fifty to 150 feet.

The beds of the Dakota formation are commonly regarded as of fresh water origin on account of the fresh water shells and abundant remains of land plants contained in them. In Texas and Kansas, however, marine forms are found and indicate marine conditions in those districts. The sandstone was probably formed in large bodies of fresh water, the materials composing it being derived from the Rocky Mountain region on the west and in part also from a land mass in what is now the Black Hills area. The waste from the land was gathered and transported by the streams and deposited in these lakes, where it gradually accumlated to form the sandstone strata.

COLORADO FORMATION

The Colorado formation, as has already been stated, is composed of the Benton and Niobrara shales and limestone. It directly overlies the Dakota sandstone and in most cases at least is conformable with it.

Benton.—Outcrops of Benton shales within the state are few, although they are known to underlie large areas in the central and northern portions. Among the fossils collected during the past summer from the marl beds at the Portland Cement Mill, nine miles north of Milton, and sent to the Smithsonian Institution for identification, was a single imperfect imprint of Inoceramus. Dr. T. W. Stanton reports that this is probably referable to *Inoceramus labiatus* Schlotheim, which species is characteristic of the Benton formation. This may indicate that at least a portion of the beds at the cement mill belong to the Benton, although some of the fossils collected from these same calcareous strata have been referred to the overlying Niobrara, as shown on a succeeding page.

The deep well at Devils Lake passed through 1,403 feet of dark shale, the lower part of which may safely be referred to the Benton, and the Jamestown well penetrated about an equal thickness of shales belonging in part to the same formation. These beds appear to thin out toward the east and north, so that they are absent from the Red River valley. At Morden, Manitoba, not far west of the valley and about fifteen miles north of the international boundary, the combined thickness of the Benton, Niobrara and Pierre is only 289 feet, which shows a marked decrease in the thickness of these strata compared with that at Devils Lake. In the eastern part of the state the Pierre shales probably rest directly on the Dakota sandstone.

The Benton is composed of blue clay shales with occasional thin bands of limestone in some places. In Nebraska the upper portion of the formation is highly calcareous and chalky and comprises beds which were formerly regarded as belonging to the overlying Niobrara.* On account of their fossils they are now placed in the Benton.

It is difficult, if not impossible, to determine the thickness of the Benton in North Dakota. This is largely owing to the fact that it cannot be distinguished in well records from the Niobrara and Pierre shales overlying it. It is probable, however, that in the central part of the state the Benton has a thickness of from 400 to 600 feet.

Niobrara.—The upper member of the Colorado formation is the Niobrara and it is often impossible to draw any sharp line of separation between this and the underlying Benton. The Niobrara, however, is usually characterized by the presence of a considerable thickness of calcareous and chalky strata.

The Niobrara beds outcrop in the northeastern corner of North Dakota along the Pembina, Little Pembina and headwaters of the Tongue rivers. These streams have eroded their valleys to a depth of 300 feet or more in the elevated region known as the Pembina Mountains, and along the sides of the valleys the Cretaceous rocks are in places excellently exposed.

At the point where the Little Pembina joins the Pembina river, on the north side of the latter stream near Mr. Mayo's brick plant, the following section is exposed. A large portion of the bluff has here recently broken away and slipped down to the bottom of the valley:

		FEET
3.	Soil and drift	6
2.	Light gray and buff, highly calcareous shale, containing layers of a slightly argillaceous chalk; these chalky beds contain abundant shells of Foraminifera, particularly *Globigerina cretacea* and *Textularia globulosa*	25
1.	Black and dark blue clay shales, passing above into a mottled gray calcareous clay or marl. The lower forty to fifty feet are covered by material which has slipped down from above and are not well exposed	290

All of the beds in the above section probably belong to the Niobrara, although some of the lower ones may be Benton.

Section at the Portland Cement Mill on the Tongue river, near the Cavalier-Pembina county line:

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*Nebraska Geological Survey, Vol. 1, p. 138.

		FEET
8.	Unexposed to top of bluff, drift in part	50
7.	Bluish gray clay shale which on weathering breaks up into thin flakes; irregularly jointed, contains iron pyrites concretions and yellow spots and blotches of iron oxide. (Pierre shale)	70
6.	Unexposed	50
5.	Black and highly carbonaceous shale, containing abundant fragments of fossils; breaks readily into thin laminae and is cut by joints and irregular cracks which are filled with gypsum. Some of these gypsum seams are vertical while others are inclined at angles of about 45 degrees. Occasional thin layers of white clay occur toward the base	60
4.	Black, carbonaceous clay shale layers alternating with white clay seams; the black shale is similar to No. 5. The white bands, which are apparently formed by the leaching of the dark shale, are from one-half to five or six inches thick and have an acid taste	6 to 8
3.	Gray clay shale, resembling No. 2, but only slightly calcareous; much stained by iron oxide, which colors the joint faces brown	3 to 4
2.	Mottled, gray, highly calcareous clay or marl; is not shaly in structure but breaks irregularly into thick pieces; when weathered it often shows laminae one-quarter to one-eighth of an inch thick and crumbles readily into thin fragments. Contains much bituminous material and when fresh has a strong petroleum odor. Fossils common, but mostly fragments, though entire fishes are found in the beds. Contains several thin seams of lignite one to three inches thick	60
1.	Yellow clay, not very calcareous, exposed at river level.	

At the base of No. 2 of the above section there is a seven foot layer which is quite uniform in chemical composition and approaches closely that of a natural Portland cement rock. A large series of analyses show that the composition of this layer lies within the following range:

	PER CENT
Silica	9 to 15
Alumina	4 to 8
Iron oxide	2 to 3
Carbonate of lime	63 to 75
Carbonate of magnesia	1 to 2.5

The marl beds above this vary widely in composition, the percentage of lime carbonate ranging all the way from twenty to seventy-five per cent. The layers very poor in lime are seldom more than one or two inches thick, while those highest in lime are usually not over two feet in thickness. These chemically different beds alternate one with another and there is no regular increase or decrease in the lime content toward the top or bottom of the section, the changes in composition being abrupt.

Highly calcareous, mottled, gray marls similar in appearance to No. 2 of the Cement Mill section were observed on the Little Pembina river near the sharp bend to the north and they have already been mentioned as occurring in the outcrop at the mouth of this stream, some thirty feet below the chalk beds.

It is interesting to note that these same calcareous shales, associated with chalk, are found farther north in Manitoba. The Niobrara formation, as described by the Canadian geologists,* comprises gray, chiefly calcareous shales, with a band of light gray chalk or mottled gray chalk marl about 200 feet thick. The beds are identified as belonging to the Niobrara by the constant presence of large numbers of Foraminifera.

The occurrence of chalk in North Dakota was unknown prior to its discovery the past summer on the Pembina river, although chalk had been found in the Niobrara of Texas, Kansas, Iowa, South Dakota and elsewhere.

For many years the text books on geology affirmed that there was no true chalk in the Cretaceous strata of America. But the Foraminifera characteristic of these white, calcareous deposits of the west and northwest have been recognized by many observers and the presence of true chalk in this country has been clearly set forth by Calvin† and others. Two species of Foraminifera which are very abundant in the chalk are *Globigerina cretacea* and *Textularia globulosa*, these and other microscopic shells making up a large part of the beds. Both of these species were readily identified in the specimens collected from the Pembina river outcrop, and leave no doubt that the material is chalk. The rock is not pure but contains some clay, as shown by the following analysis of an air dried sample of the chalk:

	PER CENT
Carbonate of lime	66.00
Carbonate of magnesium	1.40
Silica	16.06
Iron and aluminum oxides	8.65
Materials undetermined, and moisture	7.89
Total	100.00

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*Trans. Roy. Soc. Canada, Vol. VIII., Sec. IV., 1890, p. 113.
†Iowa Geol. Surv., Vol. III., 1893, pp. 213-236.

The Portland cement marls lie below the horizon of the chalk and from these beds the following fossil vertebrates are reported by F. W. Sardeson*: the toothed bird *Hesperornis*, the teleost fish *Pachyrhizodus*, and *Platecarpus*, all referred by him to the Niobrara horizon. The vertebrae of a species of *Crocidilus*† have been found in the same strata.

From No. 2 of the Portland cement mill section small specimens of *Ostrea* and *Avicula* were collected, as well as fish scales and vertebrae, which are abundant. With these was found the imprint of an Inoceramus referred to *Inoceramus labiatus* Schlotheim,‡ which is characteristic of the Benton formation. The strata containing the above fossils probably lie near the contact of the Benton and Niobrara and it is therefore difficult to refer them with certainty to one or the other. The exact position of the horizon yielding the vertebrates, with reference to No. 2 of the Cement Mill section, is not known, though they are reported to have come from the Portland cement zone.

The humerus bone and vertebrae of a Plesiosaurus were some years ago found in digging a well in the vicinity of the cement mill. These recently came into the possession of the Geological Survey and were identified by Mr. C. W. Gilmore of the Smithsonian Institution.

Chalk is composed of the more or less broken shells of Foraminifera and other marine organisms, particularly the minute disc-like bodies known as Coccoliths. The entire shells of the Foraminifera are imbedded in the fine, calcareous mud which is formed from the debris of the skeletons of various simple forms. Chalk is formed in the clear, open sea and in comparatively deep water. The bottom of the sea on which it is deposited is so situated as to be, for the most part at least, out of reach of mechanical sediments brought from the land. This condition is commonly found in deep water and at some distance from shore, where the debris from land waste is largely absent. It was, then, in such a clear, open sea and under such conditions that the chalk beds of the Niobrara were formed. The presence of some clay in the chalk deposits of North Dakota indicates, however, that a little of the finer mechanical sediment from the land was mingled with the foraminiferal, calcareous debris at the time of its deposition.

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* In personal letter to the writer.
† Identified by F. A. Lucas of the Smithsonian Institution.
‡ Fossils identified by Dr. T. W. Stanton of the U. S. Geological Survey.

The clays and marls composing the great bulk of the Niobrara are likewise of marine origin, as is indicated by their fossils. The beds were laid down in the sea, the materials which form them being derived chiefly from the waste of the land. The marls doubtless derived their lime carbonate from the abundant shells of marine organisms, many of which have been ground up and intimately mixed with the mechanical sediments, forming the calcareous clays.

The Niobrara formation, considered as a whole, is composed of gray to black clay shales, marls and some beds of light gray and buff argillaceous chalk.

The total thickness of the Niobrara in the northeastern part of the state could not be determined since the lower limits have not yet been defined. If all the beds appearing in the section at the mouth of the Little Pembina belong to the Niobrara, its thickness at that point is at least 300 feet. It is less than 200 feet at the Portland Cement Mill even if the black, carbonaceous shales (Nos. 4 and 5), overlaying the marl, are included in the Niobrara. In Manitoba the thickness of this formation varies from 128 to 545 feet.

MONTANA FORMATION

Pierre.—The Pierre shales play an important part in the geology of North Dakota, both on account of their wide distribution throughout the central and eastern portions and also because they have furnished the great bulk of the material of the drift and soils over the same region. They cover nearly, if not quite as large an area as the Laramie strata which occupy the western half of the state. The shales overlie the beds of the Niobrara ard are entirely conformable with them.

The strata of the Pierre make up a large part of the conspicuous, wooded escarpment bordering the Red River valley on the west and known as the Pembina Mountains. They appear at many points along the edge of these highlands, particularly where they have been cut into by such streams as the Pembina, Little Pembina, Tongue and Park rivers. They are well shown in the vicinity of Milton, and further south they outcrop about one and a half miles north of Niagara, along the North Branch of the Turtle river. The shales are exposed at many points along the Sheyenne river from its headwaters among the drift hills west of Devils Lake to the bend near Lisbon. At Valley

City the Pierre shales rise at least 120 feet above the river and appear along both the James river and Pipestem creek, several miles above Jamestown.

Throughout the larger part of their extent, however, the beds are buried under a greater or less thickness of glacial drift. The rock debris forming the superficial deposit is composed chiefly of fragments of the shale, mingled with some foreign material, and this indicates that the Pierre shales form the bed rock beneath the drift.

The general character of the beds is shown in the sections which follow. The first is one and a quarter miles east of Valley City, in a cut along the Soo railroad:

	FEET
4. Drift and soil	1 to 3
3. Black clay shale, with yellow iron stains in spots and blotches. Upon exposure to the weather it crumbles into thin flakes	6 to 8
2. Light gray and cream-colored clay shale, containing some layers of a rather calcareous clay	20
1. Unexposed to river	60

The light colored clays of No. 2 are readily distinguished from the dark ones above even at a distance, and the contact between them can be traced for miles along the bluffs. There is a marked difference in the way the two clays weather.

The same beds are exposed along the Sheyenne river at the sharp turn one mile south of Valley City, where the stream cuts against the bluff. One hundred feet of light gray clay shale, representing No. 2 of the above section, are exposed here, overlain by ten to twenty feet of black shale. The light colored shale breaks into thick, irregular pieces and not into thin fragments or flakes, as the black clay. The upper portion, for several feet below the dark shale, is cream-colored and more calcareous than the lower beds.

An analysis of these more calcareous, cream-colored layers gave the following result, the specimens being air dried:

	PER CENT
Carbonate of lime	75.00
Carbonate of magnesium	3.00
Silica	30.70
Iron and aluminum oxides	15.20
Materials undetermined and moisture	6.10
Total	100.00

The Pierre shales are well exposed on Pipestem creek at the abrupt bend one mile south of Parkhurst, the first station north of Jamestown on the Northern Pacific. Seventy-five feet of dark clay shales are here seen. They are cut by several sets of joints and show many yellow spots and blotches caused by iron oxide. The shales are readily broken into thin slabs with conchoidal surfaces, and under the action of the weather they crumble into thin fragments. Some nodules of iron pyrites are scattered through the beds. Similar shales outcrop on the James river five miles north of Jamestown, and at other points along the valley.

As shown in numerous outcrops the Pierre formation is composed of black, bluish, greenish and light gray shales. Some of the beds are rather calcareous and occasionally they are sandy. The shales disintegrate readily into small, flaky fragments which cover the surface to a depth of from a few inches to several feet. They commonly show yellow iron stains and are cut by joints. The shales of the Pierre are quite uniform in character throughout the state and can be readily recognized.

Fossils are found only sparingly in these strata. The more common forms which occur are *Baculites ovatus* Say, *Inoceramus sagensis* Owen, and *Scaphites nodosus* Owen. It usually requires careful and prolonged search to discover any fossils and many of the beds are barren of them.

The Pierre shales show a wide variation in thickness in different localities. They probably attain their greatest thickness in the northeastern part of the state, in the Pembina Mountain region. As previously stated, this elevated area is formed in great part of these shales, which are here at least 300 to 400 feet thick and they probably exceed this toward the west and north. Toward the east, however, they gradually thin out and are absent from the Red River valley.

The Pierre formation is a marine deposit and the materials composing it were laid down as fine mud or clay in the sea. Shales are formed of the finer debris from the land and the absence of much sand and coarse sediment indicates that the beds accumulated at some distance from the shore, where the coarser materials did not reach.

The latter are deposited near the coast and the finer and lighter detriturs is transported by the currents to a greater distance from land before settling to the bottom.

Fox Hills.—This upper member of the Montana formation receives its name, as already stated, from its prominence in the Fox Ridge or Fox Hills, lying between the Cheyenne and Moreau rivers of South Dakota. So far as our present knowledge goes it is probable that the Fox Hills sandstone appears at the surface at only a few points in North Dakota.

During the summer of 1903 members of the survey collected a brown, friable sandstone on the Cannon Ball river about eight miles above its mouth. This rock contained the fossil shells *Tancredia americana* M. & H. and *Callista* sp., possibly *Callista nebrascensis* M. & H. There are marine Cretaceous forms and the sandstone beds containing them doubtless belong to the Fox Hills formation.* Certain sandstones occurring in Emmons, Burleigh and adjoining counties have been referred by Todd† to the Fox Hills, such a correlation of the beds being based upon Hayden's statement that the Fox Hills sandstone was evident about Long Lake. But there appears to be nothing to indicate that these are not Laramie in age. Sandstone strata are not uncommon in the overlying Laramie formation, where they are formed by the local hardening of beds of sand. Such indurated sandrock, belonging undoubtedly to the Laramie, is found near Velva, Sims, capping the buttes near Dickinson, and elsewhere. In the absence of fossils it is difficult, if not impossible, to determine definitely the age of the sandstones at Long Lake, Steele and Long Lake creek, in Emmons, Burleigh and Kidder counties, but from their position and stratigraphic relations they are more likely to belong to the Laramie.

In the Turtle Mountain region outcrops of sandstone or other Cretaceous rocks are extremely rare on account of the thick drift deposits, but there is every reason to believe that the strata which do outcrop there all belong to the Laramie. The presence of Laramie coal and clays well toward the base of the Turtle Mountains indicates that the Fox Hills sandstone, if present, must lie at some depth below the surface.

A considerable area in the western part of the state is probably underlain by this sandstone but it is covered by the younger Laramie beds and the still more recent drift sheet. Across the line in South Dakota this formation has quite a wide distribution west of the Missouri, with smaller areas east of that stream.

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*Fossils identified by Dr. T. W. Stanton of the U. S. Geological Survey.

†Bull. No. 144, U. S. Geological Survey, p. 55.

The Fox Hills formation "consists largely of gray and yellow, thin-bedded sandstone, which sometimes weathers to a pink color. With these are associated incoherent sands and arenaceous clays, the whole occupying 100 to 150 feet in thickness. The sandstones are rarely more than six inches in thickness, and are frequently much thinner. They attain prominence in the topography of the country, especially in the vicinity of streams, by their durability. They are found capping cliffs and bluffs in a very clear cut and picturesque manner. They are cut by frequent joints which traverse the layers in lines usually at right angles to one another. The sandstones are frequently pierced with stems of plants standing vertically."* In South Dakota the Fox Hills beds furnish a building stone of fair quality.

LARAMIE FORMATION

No other geological formation in North Dakota is of so great economic importance as the Laramie, and no other, with the possible exception of the Pierre, covers so large an area within the state. It contains rich and practically inexhaustible deposits of coal, as well as a variety of high grade clays suitable for fire brick, pottery and ornamental and common brick. It is the sculpturing of the clays and sands of the Laramie which has given rise to the unique and picturesque scenery of the bad lands. Then, too, no other formation in the state forms the surface rock over such an extensive area, thus furnishing many excellent exposures. Not only have the Missouri and its tributaries cut deep valleys in these strata and exposed vertical sections hundreds of feet in height, but over a large portion of its extent the Laramie rocks lie immediately beneath the soil, with no covering of drift to bury them from sight.

It has been said that this formation represents one of the most interesting epochs in North American geological history. There has been much discussion regarding the age of the deposits, some geologists referring them to the Cretaceous, others to the succeeding Tertiary period. This uncertainty as to the age of the Laramie strata is due to the fact that the plant remains resemble those of the Tertiary, while the vertebrate life is distinctly Cretaceous. The formation is now regarded as holding a transitional position between those two periods, and is related to the Mesozoic on the one hand and to the Cenozoic on the other.

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*Todd, South Dakota Geological Survey, Bull. No. 1, p. 95.

The Laramie beds occupy the entire western half of the state with the probable exception of the greater portions of Bottineau and McHenry counties. So far as known at present the formation is not found beneath the drift in those two counties, although later explorations may disclose its presence. As will be seen from the map (Plate I), the Laramie extends as far east as the eastern edge of Emmons, Burleigh, McLean and Ward counties, and perhaps farther. Outcrops of the clays, sands and lignite seams are common along all the larger streams of the region—the Missouri, Little Missouri, Cannon Ball, Heart and Knife rivers with their tributaries. Perhaps the best exposures are found in the bad lands of the Little Missouri, where the conditions are particularly favorable for the study of the Laramie.

The character of the formation is best shown by the following detailed sections, taken at a number of widely separated points;

SECTION IN THE BLUFFS OF THE MISSOURI, FOUR MILES SOUTHEAST OF WILLISTON

		FEET	INCHES
13.	Drift, containing many boulders	1 to 10	
12.	Clay, light gray........................	4 to 6	
11.	Lignite seam, not well exposed	1 to 2	
10.	Clay, sandy, light gray, with yellow bands due to presence of limonite similar to Nos. 5 and 8	30	
9.	Lignite seam..........................	..	8
8.	Sandy clay shales similar to No. 5 and containing many ferruginous sand concretions	20	
7.	Light bluish gray clay, not sandy, crumbles readily into thin laminae; much softer and more easily weathered than No. 6............................	2	
6.	Clay shale with peculiar vertical fracture; is broken up into long, slender and irregular columnar pieces by numerous vertical cracks. This clay shale is harder than the clays above and below and hence resists weathering better..........................	..	10
5.	Light gray, sandy, clay shale with yellow, limonitic bands	30	
4.	Lignite seam..........................	8	
3.	Light gray, sandy clay, similar to No. 1, but has fewer concretions. Contains leaf impressions and silicified		

		FEET	INCHES
	wood. One silicified trunk twelve inches in diameter lies immediately above the coal seam (No. 2)......	50	
2.	Lignite seam	3	
1.	Light gray, sandy clay, containing abundant ferruginous sand concretions scattered through the clay; selenite crystals also numerous	30	

The base of the section is from forty to fifty feet above the river.

SECTION ON THE SOUTH SIDE OF THE MISSOURI, THREE MILES BELOW WILLISTON

22.	Drift containing large numbers of boulders.............................	5 to 10	
21.	Gray sandy clay with ferruginous sand concretions	6	
20.	Lignite seam		3
19.	Clay shale, gray, with thin lignite parting near base	4	
18.	Gray, sandy clay with some sand concretions and several thin, yellow, limonitic bands near the top.........	30	
17.	Brown, sandy clay with plant impressions...............................	1	
16.	Gray, sandy clay......................	4	
15.	Lignite	2	
14.	Sandy, gray clay......................	8	
13.	Lignite seam	..	6
12.	Gray and very sandy clay, containing abundant concretions of sandstone and lenses and bands of the same material. These concretionary masses are harder than the rest of the rock and on weathering they stand out on the face of the slope or form the cap of the earth pillars. The concretions vary in size from several inches to eight and ten feet or more	45	
11.	Clay with abundant silicious limonite nodules	4	
10.	Clay shale, brown, fissil	1	6
9.	Clay containing many limonitic nodules...............................	10	
8.	Lignite seam		1
7.	Clay, sandy, gray or yellow, contains silicified stumps of trees............	10	
6.	Lignite	1	

		FEET	INCHES
5.	Clay, light gray, not sandy	3	
4.	Lignite seam		1
3.	Light gray, sandy clay	30	
2.	Gray sandstone, fine-grained	1	6
1.	Clay, light gray (exposed)	10	

SECTION ON WHITE EARTH RIVER, ONE AND A HALF MILES NORTH OF TOWN OF WHITE EARTH

22.	Drift	2 to 6	
21.	Gray, sandy clay, with large sandstone concretions	30	
20.	Lignite seam		8
19.	Gray clay	8	
18.	Sandstone, weathering into concentric, concretionary masses, soft, gray	1	6
17.	Gray, sandy clay, with yellow, ferruginous lines and bands, not well exposed	30	
16.	Lignite seam		2
15.	Clay, gray, sandy, with sandstone concretions	25	
14.	Soft, gray, shaly sandstone	2	
13.	Gray, sandy, clay, with yellow ferruginous bands	7	
12.	Lignite and brown, fissil shale		6
11.	Gray and very sandy clay	25	
10.	Lignite seam, not well exposed	2	
9.	Gray clay containing much selenite	20	
8.	Gray sandstone	1	6
7.	Gray clay	8	
6.	Yellow clay		2
5.	Gray clay	3	
4.	Yellow, ferruginous band		⅛
3.	Gray clay	1	6
2.	Clay, brown, fissil, with some lignite		2
1.	Gray clay containing crystals of selenite	20	

SECTION AT THE BIG BEND OF THE MISSOURI RIVER TWO MILES NORTHWEST OF COAL HARBOR

38.	Drift	30	
37.	Clay shale, chocolate brown below, gray above	5	
36.	Lignite seam	3	6
35.	Clay shale, containing plant impressions	1	6
34.	Fine, argillaceous sand	8	
33.	Gray, laminated clay shale	5	
32.	Lignite seam		3 to 5
31.	Gray clay shale	5	

		FEET	INCHES
30.	Sandy, gray clay stained yellow in spots by iron oxide	6	
29.	Brown clay shale with thin lignitic partings		6 to 10
28.	Light gray clay, growing sandy above	5	
27.	Gray, sandy clay with ferruginous nodules and yellow, limonitic bands	20	
26.	Clay shale, gray and yellow in alternating layers, with thin, yellow, limonitic bands. Contains many *Unios* and gastropods including *Viviparus trochiformis*	4	
25.	Brown and black, brittle, coaly shale	1	
24.	Brown clay shale	1	
23.	Lignite seam		6 to 8
22.	Brown, clay shale with plant remains		10
21.	Lignite seam		2 to 3
20.	Clay with abundant plant impressions		2
19.	Fine, argillaceous sand	3	
18.	Gray clay shale, crumbles readily into thin flakes	1	
17.	Thin lignite seam		½
16.	Gray and yellow clay shale in alternating layers; crumbles readily on exposure to the weather. Contains *Unios* and gastropods	4	6
15.	Clay shale, chocolate brown, with fossils similar to those in No. 16	4	
14.	Lignite seam		10
13.	Clay shale, gray, weathers into thin flakes	1	6
12.	Gray and yellow, sandy clay with ferruginous nodules	10	
11.	Lignite seam with some coaly shale		8
10.	Gray clay shale	4	
9.	Lignite seam and brown, carbonaceous clay		2
8.	Gray, sandy clay, stained yellow in spots by iron oxide. Contains very many sandy, ferruginous nodules, distributed mostly in bands. The nodules stand out on the surface and fragments of them cover the slope. Also contains large sandstone concretions and lenses	31	
7.	Gray and yellow argillaceous sand	4	
6.	Gray clay, with no sand, and containing nodules of iron oxide	1	

		FEET	INCHES
5.	Lignite seam......	3	
4.	Gray clay shale........................	1	
3.	Lignite seam, entire thickness not exposed, but at least...........	4	
2.	Sandy clay shale.......................	10	
1.	Unexposed to river	15	

SECTION ON SQUARE BUTTE CREEK, IN SOUTHEASTERN OLIVER COUNTY, ONE MILE ABOVE MR. KIEBERT'S RANCH

		FEET	INCHES
11.	Soil	1	6
10.	Drift, with numerous boulders and pebbles of igneous rock; the till is composed largely of the underlying clay and sandstone...................	2 to 6	
9.	Soft, yellow sandstone; many of the beds are more or less concretionary and uneven in thickness. The rock contains much iron oxide which stains it brown in places....................	25	
8.	Dark, chocolate brown clay shale		6
7.	Sandstone, soft, yellow, concretionary.	2 to 3	
6.	Brown and yellow, sandy clay shale, alternating with yellow and gray sandstone beds, the layers varying from three to six inches in thickness	6	
5.	Soft, yellow sandstone................	1½ to 2	
4.	Hard, sandy, clay shale. This bed thins out and disappears at south end of the exposure		8
3.	Yellow sandstone, laminated above and breaking into thin slabs, more massive below..........................	2	
2.	Gray and brown clay shales alternating with yellow and gray sandstone layers, the beds varying in thickness from one to six inches. The chocolate brown shale contains fragments of carbonized wood....................	20	
1.	Sandy, gray, yellow and brown clay shale, jointed, with a few sandstone strata two to three inches thick	40	

SECTION ON THE HEART RIVER, ONE MILE SOUTH OF DICKINSON, AT THE CLAY PIT OF THE DICKINSON PRESSED BRICK & FIRE CLAY COMPANY

12. White, sandy, coarse-grained and very pure fire clay. This is composed chiefly of quartz sand, with some white kaolin clay which coats the

		FEET	INCHES
	sand grains, fills the interstices and gives the beds their white color	7	
11.	Light gray to white, very fine-grained and pure pottery clay	1 to 2	
10.	Blue, fine-grained clay	5 to 6	
9.	Gray sand, fine-grained, shows cross-lamination	35	
8.	Clay, very sandy	4	
7.	Lignite and brown carbonaceous shale	1	
6.	Sandy clay	4 to 5	
5.	Lignite seam	2 to 4	
4.	Gray, sandy clay	6	
3.	Gray, fine-grained, argillaceous sand	10	
2.	Unexposed	6	
1.	Lignite seam, exposed in bed of river	8	

SECTION IN THE BLUFFS OF THE LITTLE MISSOURI AT MEDORA

The beds are well exposed in the ravine which has cut back into the bluff just below the town.

40.	Shaly sandstone, gray weathering to yellow, finer grained than No. 39. Contains cherty layer	15	
39.	Sandstone, dark-gray, rather soft, coarse-grained, massive; forms vertical escarpment near top of bluff	45	
38.	Lignite seam and coaly shale		1 to 4
37.	Clay shale, gray and yellow	9	
36.	Lignite seam		3 to 4
35.	Clay shale		6
34.	Gray, fine-grained, shaly sandstone	6	
33.	Yellow clay shale	1	6
32.	Lignite seam		6
31.	Gray clay shale	1	
30.	Gray, sandy shale	6	
29.	Clay shale, gray	1	6
28.	Chocolate brown clay shale with thin lignite seam	1	
27.	Gray clay shale	4	
26.	Soft, shaly sandstone, gray and buff, laminated, fine-grained; in places forms hard sandstone ledge projecting beyond the softer shales above and below	15	
25.	Gray and yellow clay shales, with some sandy layers	5	
24.	Chocolate brown clay shale with plant impressions		4
23.	Lignite seam	1	6

		FEET	INCHES
22.	Clay shale, gray and yellow, with some sandy layers and a thin streak of lignite	30	
21.	Sandy shale passing above into a compact, hard, fine-grained gray sandstone. This rock forms a projecting ledge	3 to 4	
20.	Gray and yellow clay shale	5	6
19.	Fine-grained sandstone, forming projecting ledge	2	
18.	Gray and yellow clay shale	4	6
17.	Gray, fine-grained, sandy shale	6	
16.	Lignite streak and chocolate brown shales		½
15.	Gray, sandy shale and soft sandstones. In places the sandstone is cemented into hard rock, forming projecting ledge	7	
14.	Gray clay shale	1	
13.	Chocolate brown shale		8
12.	Lignite seam	1	
11.	Gray and yellow clay shale	25	
10.	Chocolate brown shale	2	
9.	Lignite seam	4	
8.	Chocolate colored clay shale with abundant plant remains, mostly stem impressions	1	
7.	Gray clay shale	3	
6.	Sandy shale and fine-grained sandstone	16	
5.	Clay shale	4	
4.	Sandy clay shale	6	
3.	Gray clay shale	1	
2.	Lignite seam	9	
1.	Gray clay shales, not well exposed, to river	40	

PICKET BUTTE SECTION, CUSTER TRAIL RANCH, ON THE LITTLE MISSOURI FIVE MILES SOUTH OF MEDORA

		FEET	INCHES
67.	Gray clay shale, growing sandy above to top of butte	12	
66.	Lignite seam		4 to 6
65.	Gray, sandy clay shale	6	
64.	Laminated, gray sandstone, rather hard, forms projecting ledge	4	6
63.	Gray clay shale	2	
62.	Brown shale containing plant impressions and shells	1	6

		FEET	INCHES
61.	Gray clay shale crumbling readily into thin flakes	6	
60.	Lignite seam		7
59.	Gray clay shale, passing above into chocolate brown shale	1	
58.	Fine-grained, soft, gray sandstone	16	
57.	Gray clay shale	2	
56.	Gray and yellow sandstone	12	
55.	Gray clay shale	4	6
54.	Chocolate brown shale		4
53.	Lignite seam	1	
52.	Chocolate brown clay shale		6
51.	Clay shale, gray	7	
50.	Brown clay shale with plant impressions		1
49.	Gray clay shale	2	6
48.	Sandstone, soft, gray and yellow, fine-grained, with thin bands of yellow, limonitic clay	20	
47.	Gray clay shale, growing sandy toward top and graduating into the overlying sandstone	2	
46.	Lignite seam, the lignite being of excellent quality	4	
45.	Chocolate brown clay shale, with plant impressions		9
44.	Gray clay shale. The lower portion of this member and No. 43 below contain great numbers of selenite crystals. Some of these are eight to ten inches long and they are scattered thickly through the clay	4	6
43.	Chocolate brown clay shale with abundant plant impressions		6
42.	Lignite seam, the coal of good quality	6	
41.	Brown clay shale, similar to No. 43		8
40.	Gray clay shale	5	
39.	Black, coaly shale, with some lignite		3
38.	Soft, gray sandstone, fine-grained and showing cross-lamination; contains pyrite nodules which have altered extensively into limonite. It has layers of brown, ferruginous, hard sandstone, forming projecting ledges	34	
37.	Lignite seam	5	
36.	Chocolate brown clay shale with carbonized wood		6

		FEET	INCHES
35.	Soft, gray sandstone, fine-grained, with several bands of clay two or three inches thick	5	
34.	Gray, sandy clay shale	1	6
33.	Thin lignite seam		½
32.	Gray clay shale		11
31.	Sandstone, soft, fine-grained, gray	1	2
30.	Gray and yellow clay shale	1	
29.	Soft, gray sandstone, fine-grained	1	6
28.	Clay shale, gray and yellow	6	
27.	Brown clay shales with thin lignite parting		3
26.	Lignite seam		5
25.	Chocolate brown shale with plant remains	1	
24.	Gray clay shales	5	
23.	Gray, soft, fine-grained sandstone	4	
22.	Sandy clay shales, yellow and gray	3	
21.	Sandstone, soft, gray	4	
20.	Gray and yellow clay shales, non-arenaceous, and sharply marked off from sandy beds above and below	2	6
19.	Soft, gray, fine-grained sandstone	6	
18.	Yellow and gray clay shales		10
17.	Lignite seam, with some selenite crystals		2 to 3
16.	Chocolate brown clay shales		4
15.	Clay shales similar to No. 13, with yellow band at bottom	5	
14.	Gray, fine-grained sandstone	6	
13.	Gray clay shale, soft and crumbles readily into thin fragments; yellow band at top	2	
12.	Brown clay shale	1	
11.	Black, coaly shale with some lignite		9
10.	Chocolate brown, sandy shale, with carbonized wood	3	
9.	Gray, soft, shaly sandstone, fine-grained and laminated; contains pyrite nodules partially altered on surface to limonite	4	
8.	Alternating layers of gray and yellow clay shale containing fragments of shells	4	6
7.	Shaly sandstone, yellow, fine-grained	1	
6.	Gray clay shale		5
5.	Chocolate brown, coaly shale with some lignite		6
4.	Yellow clay shale		10

		FEET	INCHES
3.	Chocolate brown shale with carbonized wood		1 to 2
2.	Gray clay shale	5	
1.	Unexposed to river	15	

It will be noticed that in the above section there are no less than twelve seams of lignite, varying in thickness all the way from one-half inch to six feet, and all occurring within a vertical range of less than 260 feet.

SENTINEL BUTTE SECTION

29.	Alternating layers of highly calcareous gray clay and very fine-grained, compact, brittle, gray limestone, finely laminated and more or less silicious. Some of the sandstone beds weather into thin laminae, one-sixteenth of an inch thick and less	7	
28.	Very calcareous, gray clay, weathering to a greenish color	18	
27.	Gray, hard sandstone	40 to 50	
26.	Gray and yellow, sandy clay	25	
25.	Brown clay and thin seam of lignite	1	6
24.	Gray and yellow, sandy clays	48	
23.	Lignite seam		6
22.	Soft, fine-grained, argillaceous sandstone	12	
21.	Brown and gray clay shale containing many selenite crystals	4	
20.	Soft, fine-grained sandstone	1	
19.	Lignite seam	1	to 18
18.	Chocolate brown clay shale, with carbonized wood	1	
17.	Bluish gray clay	10	
16.	Gray sand, cemented in places into soft sandstone	12	
15.	Not well exposed, but probably clay shale	50	
14.	Lignite seam		2 to
13.	Gray sandy clay	32	
12.	Gray clay shale with no sand	2	
11.	Lignite seam	6	
10.	Sandy clay shale, colored brown above	5	
9.	Fine, gray sand	4	
8.	Gray, sandy clay shale, containing nodules, similar to No. 6	14	
7.	Finely laminated sand	4	

		FEET	INCHES
6.	Gray, sandy clay shale with ferruginous bands	8	
5.	Chocolate brown, sandy clay shales	1	
4.	Gray clay shales with no sand	5	
3.	Sandy, gray clay, containing abundant silicious iron nodules, arranged mostly in bands at certain horizons; these hard nodules project from the surface of the softer clay, and also cap small clay columns	20	
2.	Unexposed, includes some sand	20	
1.	Lignite seam, outcropping in bottom of ravine near the east end of the butte, exposed	20	

Nos. 28 and 29 of the above section are probably Tertiary.

The foregoing sections may be taken as representative of the Laramie formation. They show that it is composed of alternating beds of clay and sand, together with seams of lignite. In places the sand layers are cemented into a firm, hard sandstone, but commonly they form incoherent beds, readily crumbling in the hand. These arenaceous strata, however, resist the action of weathering agencies better than the clays and their outcropping edges form vertical ledges, often projecting beyond the clays. The presence of the sandy beds can thus commonly be detected at a distance by the character of the slope.

Probably two-thirds of the thickness of the Laramie is made up of clays, though this varies in different places. These clay shales range in composition from very pure clays through those containing an increasing percentage of sand to beds with only a small proportion of clay. The argillaceous strata thus graduate into the sandy layers through every intermediate mixture of clay and sand, and we have sandy clays and clayey sandstones. Many of the so-called clays are, strictly speaking, impure sandstones. In some cases the change from clay shale to sand is abrupt, in others it is gradual, the clay becoming more sandy near the line of contact.

One of the most marked features of the Laramie is this rapid alternation of sand and clay strata, and the frequent occurrence of beds of lignite. The colors of the clay are white, gray, yellow, brown and red, the grays and yellows predominating. The brown layers are rich in plant remains, and it is to the presence of this carbonaceous matter that they owe their color. These

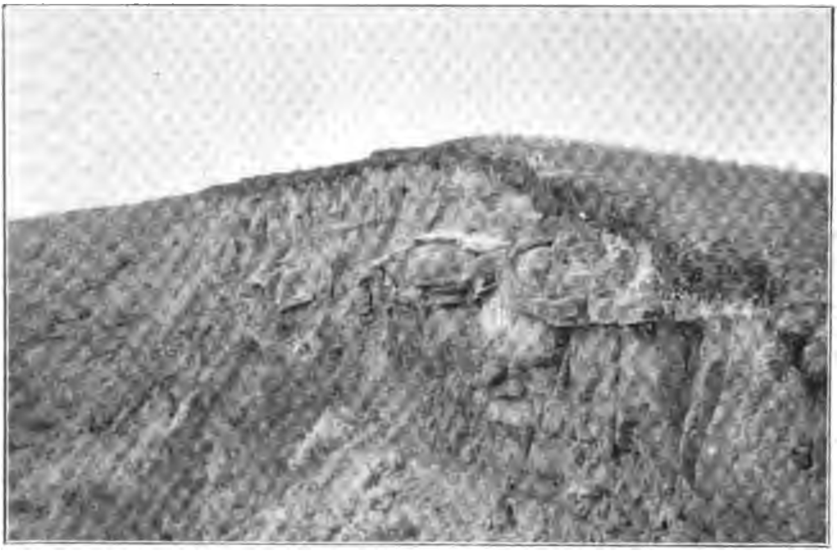

Fig. 1. Large sandstone concretions in the Laramie beds. The concentric layers are well shown. On Square Butte creek

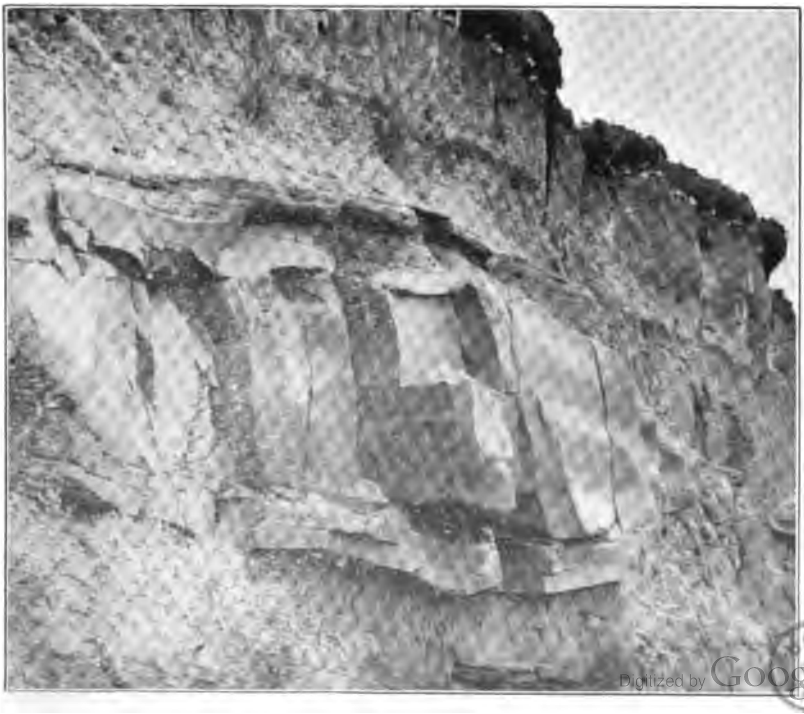

Fig. 2. A nearer view of one of the large sandstone concretions

varied colors give the formation its marked banded appearance and add greatly to the beauty and variety of the landscape.

Crystallized gypsum or selenite is common in the clay and in some layers this mineral is very abundant. It is particularly liable to occur in the brown layers immediately beneath the lignite seams, as shown in the Picket Butte section,.where a clay bed (No. 44) is packed full of crystals of gypsum. The crystals are often very much elongated, some being found eight and ten inches in length, and are seldom perfect, the faces being more or less etched.

Of still more frequent occurrence are the ferruginous nodules and concretions, composed either of iron pyrites or of limonite. They usually contain more or less silicious or argillaceous material and after exposure to the weather stain the clay about them yellow. Many of the clay slopes are thickly dotted with these nodules and concretions of all shapes and sizes up to several feet in diameter. Thin, impure, limonite or clay ironstone bands, yellow in color, are not uncommon in the clays.

Another feature of the Laramie formation is the presence of silicified wood, often preserving very perfectly the original structure of the trees. Large stumps several feet in diameter and fragments of the trunks and branches are common.

Beds of sand, sometimes hardened into a firm sandstone compose a large part of the Laramie formation. The sand varies from coarse to fine and in color is usually some shade of gray, though yellows and browns are found. Mingled with the sand is a varying proportion of clay, so that it passes into an argillaceous sand and sandy clay.

A marked characteristic of the sandy strata is the presence in them of sandstone concretions and lenses. These are made up of concentric layers, are much harder and more compact than the inclosing mass and are frequently of great size, some being observed twenty to twenty-five feet in diameter. Many resemble large lenses of sandstone but their concentric structure shows their true character. On the Custer Trail Ranch, near Medora, curious log-like concretions were observed. Three of these lay parallel to each other a few feet apart, with a length of twenty to thirty feet and a diameter of two to four feet. They resemble saw logs in appearance and size and are divided into sections by transverse joints. These are shown in Plate XXIX.

Similar log-like concretions in the Laramie beds of northwestern South Dakota have been described by Todd.* Occasionally the sand strata are cemented into a hard, firm sandstone, like that occurring near Velva and Sims, capping the buttes in the vicinity of Dickinson, Gladstone and elsewhere. The top of the Laramie formation is often composed of beds of sandstone. These are well shown on the summit of Sentinel Butte, where they are forty to fifty feet thick and form vertical cliffs, with great blocks of the same material at their base. This upper sandstone is also well developed farther south in the Cave Hills, near the boundary between North and South Dakota. In most of these sandstones the cement which holds the sand grains together is silica; but in the rock found near Velva it is carbonate of lime. The sandstone is either in thin layers two to six inches in thickness or in thick, massive ledges.

The most striking characteristic of the Laramie is the large number of lignite seams contained it it. Some sections along the Little Missouri show no less than twelve within a thickness of 250 feet, ranging all the way from an inch to six feet and over. If we add to this number the five seams which outcrop in Sentinel Butte it makes at least seventeen lignite veins between the river level at Medora and the top of that butte, a vertical distance of about 860 feet.

The frequency of the seams and their aggregate thickness are well shown in the records of the deep wells at Medora and Dickinson.† The Medora well passed, through 941 feet of Laramie strata without reaching their base and encountered no less than seventeen lignite seams with a total thickness of more than sixty feet. The Dickinson well had a depth of about 1075 feet and penetrated sixteen seams, their aggregate thickness being about fifty-five feet. The lignite does not appear to be confined to any particular horizon or horizons, but the seams are distributed quite uniformly throughout the formation. They vary in thickness all the way from an inch to forty feet. Seams from six to ten feet thick are common and thinner ones are of still more frequent occurrence. Where a bed of lignite is followed for any considerable distance it is found to thin out and finally disappear. It may be replaced further on by another seam either at the same level or at a higher or lower elevation. This want of persis-

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*South Dakota Geol. Surv., Bull. No. 2. p. 59.

†Darton, Seventeenth Ann. Rep. U. S. Geological Survey, pt. 2, p. 663.

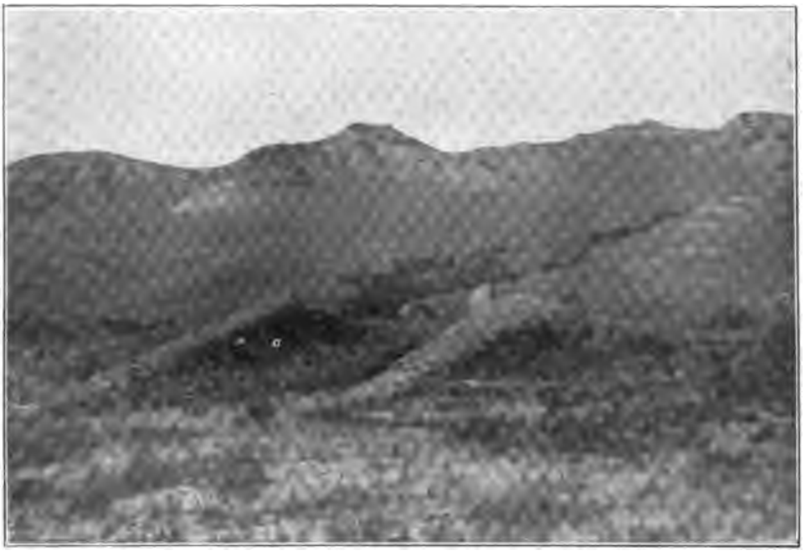
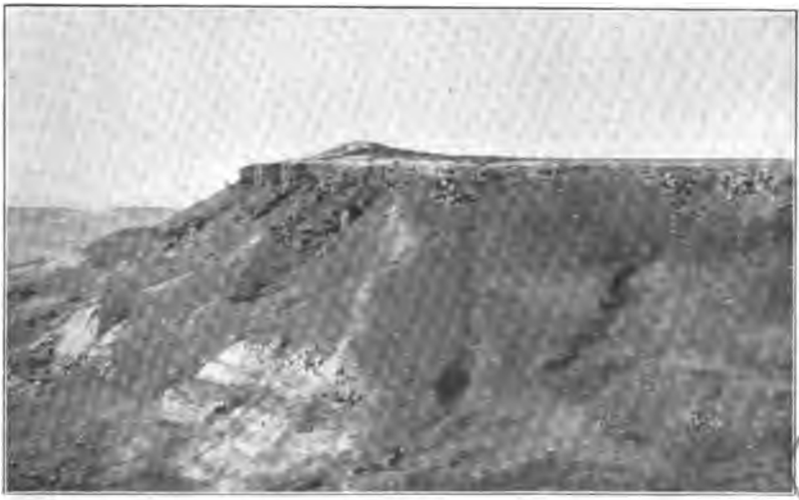


Fig. 1. Large log-like concretions in the Laramie formation. Custer Trail ranch near Medora



UNIV. OF MICH.

Fig. 2. The flat summit of Sentinel Butte showing mound of Tertiary beds at one end

tence not only in the lignite beds but in the other strata of the Laramie, is a notable feature of these deposits. Many layers thin out in less than a mile, while others may be traced several miles before they disappear and are replaced by others. The lignite seams thus have the shape of flattened lenses, thicker at the center and growing thinner toward the edges. To a greater or less extent they overlap each other. Since they do not persist over very large areas it is not safe to correlate seams in exposures separated by more than a few miles.

Another feature of the Laramie clays and sands which cannot fail to attract the notice of even the casual observer is the immense quantity of burnt and fused clay seen on every hand, wherever there are extensive outcrops of the beds. This red scoria, as it is commonly called, is merely clay which has been subjected to the great heat produced by the burning lignite seams. The latter take fire by spontaneous combustion, or probably in some instances from prairie fires, and burn often for many years. This burning of the lignite has doubtless been going on ever since the formation of the seams and has resulted in the production of a suprisingly large amount of red scoria. Bands of this material may be traced for miles along the bluffs of the Little Missouri and represent the horizons of burned out lignite seams, the adjoining clays having been burned and more or less fused as though in a brick kiln.

The Laramie beds have a thickness of at least 1,800 feet in the western part of the state. The Medora well with its depth of 941 feet did not pass through them and Sentinel Butte rises 860 feet above the curb of the well. This is perhaps the maximum thickness of the formation in North Dakota and it grows thinner toward the east until it is only a few hundred feet and less beyond the Missouri river.

Fossils are found in the Laramie strata at a number of localities. They were observed in the beds exposed in the clay pit of the Minot Coal and Brick Company, one mile below Burlington, the fossiliferous beds which occur here being well toward the base of the formation; along the Missouri near Coal Harbor; in the bluffs of the Little Missouri at the Custer Trail Ranch, near Medora, and elsewhere.

The following fossils were collected from the Laramie strata.*

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*Identified by Dr. T. W. Stanton of the United States Geological Survey.

Corbula mactriformis M. & H.
Viviparus trochiformis M. & H.
Goniobasis nebrascensis M. & H.
Unio sp. cf. *Unio priscus* M. & H.
Campeloma producta White.
Campeloma multilineata M. & H.

The first four species in the above list are from No. 62 of the Picket Butte section, five miles south of Medora, the bed containing them lying 230 feet above the Little Missouri. The last four were found at Coal Harbor at an elevation of eighty-five to 100 feet above the river.

At a number of points the Laramie contains abundant leaf impressions, among which the following have been identified:

Ten miles north of Minot;
Sequoia angustifolia Lesq.
Sequoia Langsdorfii (Brongniart) Heer.
Sequoia brevifolia Lesq.
Near Coal Harbor;
Credneria (?) *daturaefolia.*
Phyllites cupanioides Newberry.
Celastrus (probably).

The fossil leaves of the following species of trees were collected by Professor T. H. Macbride from the Laramie beds of the bad lands of the Little Missouri.*

Platanus nobilis Newberry.
Populus cuneata Newberry.
Juglans woodiana Heer.
Corylus grandifolia Newberry.
Carpinus betuloides Ung (?)
Persea (?)
Ficus (?)
Populus glandulifera Heer.
Cornus rhamnifolia O. Weber.

The Laramie formation has a very wide distribution throughout central North America and originally formed a continuous deposit about 2,000 miles long from north to south, with a width of more than 500 miles from east to west. It extends from Mexico far into Canada and is found on both sides of the Rocky Mountains. Their fossils show that the beds were, in large part at least, laid down in fresh water. Their origin is well set forth by White in the following paragraphs, taken from his correlation paper on the Cretaceous.*

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*The Little Missouri Bad Lands; Pop. Sci. Mo. Vol. 22, 1883. pp. 634-642.

"The Laramie sea is understood to have occupied a very large portion of the area which in the immediately preceding epoch was occupied by the marine waters in which the Montana formation was deposited, and that at its close the waters of the Laramie area became more or less completely surrounded by land resulting from an elevation of sea bottom above water level. Its waters consequently became partially freshened by the surrounding surface drainage, producing a habitat in which it was impossible for true marine forms to live, but which was a congenial one for those whose remains we find there. Thus was recorded a great physical, as well as a great biological, event in the geological history of the continent, our estimate of the importance of which is enhanced when we remember how great was the geographical area over which it occurred."

"It is reasonable to assume that the habitat of many of the vertebrate and other land animals which existed within and around that area before the event referred to occurred was not made uncongenial by its occurrence. But be that as it may, the strata which physically constitute such geological horizons as I have defined in this case are the result of sedimentation in great bodies of water, and physical changes which altered the conditions relating to those bodies of water and materially affected the character of their denizens, were leading events in geological history."

"By some persons the opinion has been held that during the Laramie epoch proper, open sea waters made occasional incursions at different places upon the area occupied by the non-marine waters whose fauna characterizes the Laramie formation, but although the frequent alternation of strata bearing brackish water fossils with those bearing only fresh-water forms show that within certain districts brackish waters alternated with fresh, I have, in my extensive examinations of this for mation, never detected any evidence of the incursion of open sea waters. The opinion referred to, which I think has not yet been demonstrated, has perhaps arisen from a supposed identification of coal-bearing strata of the upper part of the Montana formation with similar coal-bearing strata of the Laramie. Because it is my present belief that all true marine waters were withdrawn from the interior portion of this continent at the beginning of the Laramie epoch, no true marine strata are in this memoir recognized as belonging to the Laramie formation."

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*Bull. No. 82, U. S. Geological Survey, pp. 263, 152.

"While I am not now prepared to admit that the open ocean made incursions upon the great Laramie inland sea after it had become established as such at the close of the Montana epoch, it is reasonable to infer that it had somewhere a more or less restricted outlet to oceanic waters until all the area which it had occupied became in part dry land and in part the bed of the great fresh water Tertiary lake or lakes which immediately succeeded it. What we now know of the various epeirogenic movements which resulted in the production of the present continent leads me to believe that such an outlet, if one existed, was at the southern end, and this suggestion is supported by certain paleontological conditions which have been observed in Laramie strata in the Texan and North Mexican regions. That is, certain fossil forms have been observed in those strata which seem to indicate a greater saltness of the water in which they were deposited than prevailed elsewhere in the Laramie sea; but these observations are too incomplete to be confidently relied upon in an inquiry of this kind."

TERTIARY

Strata younger than the Laramie and probably belonging to the Tertiary occur on top of Sentinel Butte, immediately overlying the sandstone. At the west end of this flat-topped butte is a low mound rising from twenty-five to thirty feet above the level surface. It is formed of a very light gray calcareous clay or marl with a faint greenish tinge, in which there are several thin layers of a nearly white limestone. Resting directly on the sandstone are eighteen feet of the light-colored marls and above these occur alternating layers of calcareous clay and limestone with a total thickness of seven feet. The latter is very fine-grained, brittle, compact, somewhat argillaceous, and a few of the beds contain much silica. The limestone is finely laminated and on exposure to the weather separates readily along the lamination plains into thin laminae less than one-sixteenth of an inch thick. The limestone layers vary from one-half to two inches in thickness and as previously stated are quite siliceous in places.

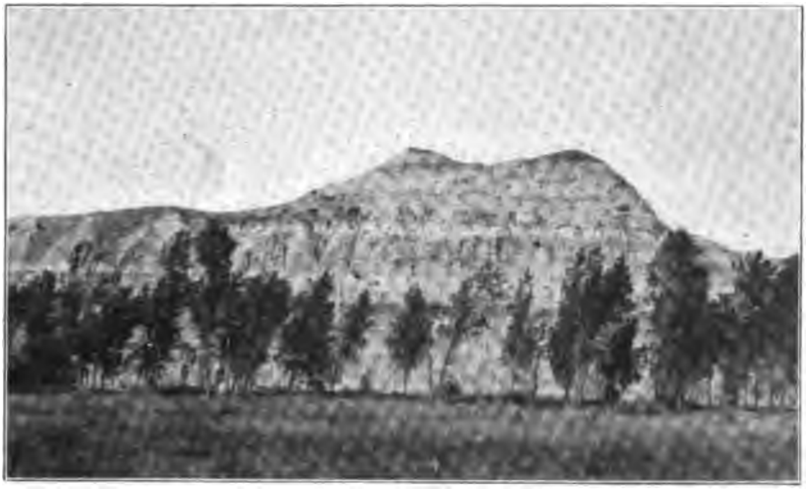

Fig. 1. Bluffs along the Little Missouri a few miles above Medora

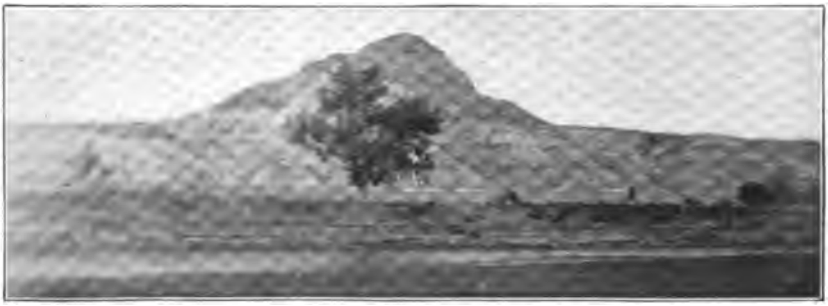

Fig. 2. A butte on the Little Missouri, the river the foreground. Custer Trail ranch near Medora

The beds exposed in this mound are unlike any seen in the underlying Laramie formation and it seems not unlikely that they belong to the Tertiary. The apparent absence of fossils from these strata, however, makes it impossible to determine with certainty their age. Similar beds occur on top of the Slim Buttes and Cave Hills, not far south of the North Dakota boundary, and on account of their fossils are considered by Todd as of Miocene age.* From the close resemblance of the beds on Sentinel Butte to those farther south and from their similarity of position they are referred provisionally to the Miocene division of the Tertiary.

The level surface forming the top of the butte is thickly strewn with angular fragments of chalcedony. These are extremely abundant and in many places form a stony pavement several inches thick. Their angular and irregular shapes suggest that they were formed as siliceous nodules or veins in an overlying formation which has been removed by erosion. The beds in which the chalcedony formerly occurred have been removed, leaving that mineral behind. The action of frost, changes of temperature, and other agencies have caused the nodules and vein material to be broken up and reduced them to angular fragments.

Todd states that "flat pieces of chalcedony, which have come from the veins of the Tertiary beds" are abundant in western South Dakota.†

PLEISTOCENE FORMATIONS

Drift.—The larger part of North Dakota is covered to a greater or less depth by a peculiar deposit known as glacial drift. It is very different in appearance and origin from the geological formations previously described and forms a mantle which buries from view the older rocks. The drift is composed of clay, sand, gravel and boulders mingled together to form a heterogeneous deposit. The chief constituent is a stiff blue or gray clay through which are scattered numerous pebbles and boulders of granite or other igneous rock. It is commonly known as boulder clay or till and nearly all of the boulders and smaller rocks differ from the underlying strata, having been transported from distant localities where ledges of such rock occur. Another peculiarity of the pebbles and boulders of the drift is that many are smoothed, polished and scratched on one or more sides.

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*South Dakota Geological Survey, Bull. No. 2, p. 62.

†South Dakota Geological Survey, Bull. No. 1, p. 121.

The question naturally arises as to the origin of the drift, and a brief discussion of this will be in order here. It was formed by a continental ice sheet or glacier which once covered the northern part of North America just as Greenland and the Antarctic regions are today covered by vast ice caps. This glacier extended as far south as Long Island, the Ohio river at Cincinnati, and the Missouri river, in Missouri. It entered eastern Kansas and Nebraska, South Dakota, and covered all of North Dakota except several counties in the southwestern corner. The drift represents the materials that were gathered up by the ice sheet as it advanced over the land, were accumulated beneath the ice, and were left behind when it melted. The foreign boulders and pebbles of the drift have been transported from the north and left, often hundreds of miles from their source. Most of the granite boulders of this state have been brought from Canada in this manner. The polished and scratched faces found on so many of them, particularly the smaller ones, were formed when the rock fragments were frozen in the bottom of the ice and were carried along between the heavy ice sheet and its rocky bed, wearing down, smoothing and striating both the pebbles and the rock bed over which they passed.

Recent studies of the drift in the United States have disclosed the fact that there are not one but several distinct sheets of drift, produced by different ice invasions. For many years it has been known that there was an older and a younger drift and investigations in the Mississippi valley region, particularly in Iowa, have established the presence of five separate and distinct drift sheets. Beginning with the first and oldest these have been named the Albertan or pre-Kansan, Kansan, Illinoian, Iowan and Wisconsin drift formations. Between the deposition of these various sheets the ice retreated for a time and these interglacial intervals are marked by vegetable accumulations representing ancient forests and soils, often many feet in thickness, and by heavy deposits of gravel and sand laid down by the streams flowing from the melting ice.

Considerably more than half of North Dakota is covered by the youngest of the drift sheets, the Wisconsin, whose border is marked by a conspicuous belt of irregular hills and hollows ten to fifteen miles wide, constituting the Altamont moraine, as it is called. This was formed along the edge of the ice where it remained stationary for a time, the rock debris carried by the glacier being accumulated and heaped up into the morainal drift hills, which are often dotted with numerous large boulders. This moraine has been traced across the state from north to south; it traverses Ward county, from northwest to southeast, about thirty-five miles west of Minot keeps the same direction through McLean county, turns south through eastern Burleigh county, crosses northeastern Emmons and after making a loop to the east into Logan and McIntosh counties again enters the southeastern corner of Emmons, whence it continues into South Dakota. The Northern Pacific crosses the Altamont moraine between Driscoll and Sterling.

Lying west of the moraine is an older drift sheet which has been regarded as the Kansan. There is, however, reason to doubt whether it is as old as the Kansan, since it has few or none of the characteristics of that drift sheet as found in other states, having every appearance of being much more recent. It is quite fresh and unweathered, is light gray in color where exposed in railroad cuts and elsewhere, and its surface has undergone very little erosion, being poorly drained in many places and containing many lakes. The pebbles of granite and other ignious rock are noticeably fresh, rotted and decomposed pebbles being very rare. In all these respects this extra-morainal drift is strikingly different from the typical Kansan. It is possible, however, that this difference is due to the semi-arid climate of the region, the weathering effect on the drift of the dry atmosphere being much less than farther south in Iowa, Kansas, and other states where there is much more moisture.

Yet it may be that this drift is younger than the Kansan, as it has every appearance of being, and it is perhaps an earlier Wisconsin drift than that occurring within the Altamont moraine. More work will be required, however, before the age of this extra-morainal drift can be fully determined.

This glacial deposit is not bordered by any terminal moraine but thins out toward the edge so that the boundary is not well defined. So far as our present knowledge goes this older drift sheet extends from thirty to fifty miles or more west and south of the Missouri river. Over much of the area beyond the river it is thin and has modified but slightly the preglacial topography.

The thickness of these glacial deposits varies within wide limits, being all the way from a few feet to several hundred feet. In the eastern part of the state it is shown by wells to be commonly from 200 to to 300 feet thick, and it is probable that these figures also apply to the central part of the region. Wells pass through 220 feet of drift at Fargo,. 250 at Casselton, 310 feet near Grandin and Kelso and 298 feet at Grafton.* The Grand Forks well penetrated 380 of drift and lacustrine deposits before reaching bed rock.

Both the older and newer drift sheets are exposed at numerous points throughout the state. Perhaps the best exposures are found in cuts along the railroads, such as those west of Minot along the Great Northern, or on the Northern Pacific between Driscoll and Sterling, where the railroad crosses the Altamont moraine.

Lacustrine Deposits.—Deposits laid down in extensive lakes which once covered large areas in North Dakota also deserve notice in any discussion of the geological formations of the state. The remarkably fertile lands of the Red River valley are formed of sediment which was deposited in old glacial Lake Agassiz. This vast body of water formerly covered eastern North Dakota, northwestern Minnesota and a large portion of Manitoba, having an area of 110,000 square miles, or more than the combined area of the Great Lakes. The streams emptying into Lake Agassiz were loaded with sediment which was laid down over the floor of the lake to form the sandy clay or loam which overlies the thick drift sheet of the Red River valley. Similar lacustrine deposits are found south and west of the Turtle Mountains, having been formed in another smaller glacial lake, known as Lake Souris, which once occupied that region. It extended west and south as far as Minot and Velva, east as far as Rugby and north across the international boundary in Manitoba, covering the larger part of Bottineau and McHenry, and adjoining portions of Rolette, Pierce and Ward counties. Deposits of like origin but of less extent occur in the southeastern part of the state.

Alluvial Deposits and River Terraces.—Among the most recent formations are the alluvium and gravel terraces found along most of the streams, particularly the Missouri. The alluvium occurs on the lowlands or flood plains forming the bottoms of the valleys and is seldom more than twenty to thirty feet above the river level. The deposit consists of sand or clay, or a mixture of the two, and represents the sediment laid down by the streams in time of flood. All of the important rivers of the state have developed flood plains varying in width from a fraction of a mile to several miles and formed of alluvium, which constitutes the rich soil of these bottom lands.

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*Upham, Mons. No. XXV, United States Geological Survey.

Of similar origin are the gravel terraces bordering most of the streams and lying from twenty-five or thirty to one hundred feet above the water. On the Heart river, a few miles west of Mandan, the James at Jamestown and the Sheyenne at Valley City, extensive gravel pits have been opened in these deposits and the material removed for railroad ballast. These gravel terraces represent the remnants of former flood plains which have been left at their present elevations by the down cutting of the rivers, the latter having eroded their channels to a greater or less depth below the level at which they once flowed. At the time of the melting of the ice sheet the streams flowing from it carried great quantities of gravel and sand which they deposited along their courses, building up the floors of their valleys and forming broad flood plains. Subsequently when the supply of sediment was reduced these rivers began to lower their channels in the flood plains and the latter remain as terraces.

STREAM MEASUREMENT AND RUN-OFF OF STREAMS IN NORTH DAKOTA

By

E. F. CHANDLER

METHODS OF STREAM MEASUREMENT

Accurate or even rough measurements of the water flowing in rivers, creeks, and other streams are very infrequent in comparison with measurements of the land that borders the streams. The most definite call for land measurements arises for the purpose of fixing the price of this real property, yet at all times there is in the owner's mind a fairly precise idea of the magnitude of his possessions, and he has at least approximate methods of measurement whereby he can estimate the area of each portion of his farm; he will tell you how many acres have been plowed, how much has been seeded for each crop, and so on, as long as desired. It is a necessity if he would carry on his work intelligently and to advantage. He can probably at a single glance estimate within twenty-five per cent the area of a field or tract that falls under his eye.

If, however, he were called upon some day to estimate the amount of water flowing in a creek passing across his farm, he might find himself unable to fix a figure that was not ten times larger or smaller than the facts. Any estimate that might be desired concerning the length of time it would occupy for the stream to fill some proposed tank or reservoir would find him entirely at a loss. He would hardly know whether to say five minutes or five weeks. There are so many factors to take into consideration that the task seems difficult. "The operations of measuring the volume of a flowing stream, although not complicated, possess an element of mystery to the average citizen, largely because he has not been accustomed to consider fluctuating quantities. It is possible to form a very definite conception of the amount of water standing in a pond or reservoir, but in the case of a stream the quantities considered are of water in motion, and therefore another and somewhat novel element enters, that of time."*

The width of the stream must be noted, and this, especially for a large stream, is not readily done by a person accustomed to walking on the dry land; appearances deceive him. The depth must be known, and here again appearances are often misleading. If the stream be shallow a small error in estimate of depth leads to disproportionately large errors in the result. In the muddy streams of North Dakota, small or great, it is rarely that the eye is a guide. Lastly the speed of the stream need be known; and here great uncertainty again arises in the observer's mind; even if there were mile-posts along the bank, floating objects move so irregularly, now speeding down the center of the channel, now lingering in an eddy or lodging on the bank, that no definite result seems readily attainable.

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*F. H. Newell, Irrigation in the United States, Chapter 3.

These difficulties arise, however, in part from lack of experience, from never having given any consideration to methods of measurement. Land is real property, to be definitely measured and individually owned and to be the chief part of one's wealth. But water, even if hardly "free as air", was classed with the rain that falls alike on the just and the unjust, a boon to which no one man can acquire title; its ownership or sale being unusual; its measurement seemed unnecessary and methods were scarcely developed until recently.

"It is to furnish information upon which to base estimates of available water supply that the Hydrographic Division of the United States Geological Survey has been, during the last fourteen years, collecting data in regard to the flow of the rivers in the United States, and their variation from season to season and throughout a series of years. The necessity for such data is frequently brought to the attention of the engineer, sometimes in a most startling manner. The lack of this information frequently leads to the most disastrous mistakes in the construction of hydraulic works. One of the best examples of this in the design of a hydraulic plant was the construction of a dam and water-power plant at Austin, Tex. After an expenditure of $1,600,000 it was found that a grave mistake has been made in the low-water flow. The works were constructed by the city in accordance with a vote of the citizens of Austin in 1890. It was estimated that 14,000 horsepower could be developed, and the people felt that their city was to become a great manufacturing center. No hydrographic data had been collected, except from the hazy memory of the "oldest inhabitant." In the spring of 1890 a measurement of flow giving 1,000 cubic feet per second was taken as the minimum. This estimate was more than five times too great, as was shown by subsequent measurements. An error of 500 per cent had been made in the estimate, but this was not ascertained until the works were nearly completed.

Mistakes of this kind have occurred in every part of the country in hydraulic works. The Sweetwater dam in California is a good example of a project carried through on insufficient data. The dam was built after a series of wet years and was soon after filled to overflowing, so that increased spillways were constructed, but since that time the water in the reservoirs has never reached an elevation near the crest of the spillways, and during most of the time there has been the greatest scarcity of water.

The Bear Valley dam is a more marked case, as the reservoir formed by the dam has been practically dry for several years, so that wells have been driven in the bottom of it.

The Gila Bend, Arizona, project is another example of the expenditure of a large sum—$900,000—upon insufficient data, and subsequent abandonment of the scheme. In this project the dam was carried away before its completion, but if it had been completed the scheme must have proved a financial failure.

Many diversion canal projects for irrigation have been either partial or complete failures on account of shortage of water; that is, developments have been made far beyond the capacity of the stream.

A great number of waterpower plants have been constructed upon insufficient data, and later, auxiliary steam has been found necessary. Allowance was not made in the original estimates, so that in a number of instances the project has been found unprofitable. Knowledge of the flood flow is also of great importance in designing the dams and waste ways.

The measurement of the larger streams of the United States is an important undertaking, and capital will be invested in power developments, irrigation, sanitary and other hydraulic works more freely when information as to the flow of the streams is available. In making measurements of streams it is of course desirable that rapid and economical methods be used, if such are of sufficient accuracy." *

The usual methods will be outlined here, with special attention to the simpler methods that are readily available for use by the man without special technical training, without elaborate instruments or long computations, if he desires to obtain a basis for rough estimates of stream flow for any use; if, for example,

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*H. A. Pressey: Observation on the flow of rivers in the vicinity of New York City.

it is desired to know whether some spring or creek can possibly irrigate a whole township or whether it is absurd to consider it as a means for irrigating more than a garden-patch.

There are three methods of measurement in general use: first, by current-meter; second, by weir; third, by floats.

The first and most elaborate method, by current-meter, is the one used customarily by the United States Geological Survey, but is not convenient except for those regularly employed in the business of stream measurements. The current-meter is an instrument which measures the velocity of the water by means of a wheel that is lowered into the water and revolved by the current. This wheel may be shaped like the screw propeller of a steamship, or like the wheel of an ordinary windmill, but in the most approved form consists of several cups arranged on the circumference of a circle about six inches in diameter, all opening in the same direction around the circumference. When placed horizontally in the water, this wheel (like the ordinary form of whirling cup anemometer for measuring the speed of the wind,) is revolved by the current catching in the interior of the cups and is turned with a speed very nearly proportional to the velocity of the current. This relation is accurately determined for all the various patterns of meter, (each turn of the wheel indicating from two to five feet flow of water, according to the size and form of the wheel) so that from a count of the revolutions of the wheel the speed of the current is definitely known. Suitable weights and rudder-vanes are attached for sinking the meter into the stream and holding it steady, and an electric connection or other means is used to indicate to the person operating it how many revolutions are made.

The speed of flow of a stream is not everywhere the same, but it is least at the bottom, and greater near the surface. At mid-depth the velocity will evidently be nearly the average for the whole channel, but is found to be slightly greater than the average except in very shallow channels. In an ordinary unobstructed channel the average velocity will be found at about six-tenths of the whole depth below the surface, or in deep smooth flumes at two-thirds the whole depth.

A suitable place for the use of meter is selected, where the current is without eddies, fairly uniform, and as nearly as may be of an even speed from one side of the stream to the other, preferably on a straight stretch, and necessarily where the channel has a reasonably even cross section (width and depth) for some little distance and is not obstructed by rocks, logs, brush, or vegetation. At a favorable place in the middle of this stretch the measurement is made on a line perpendicularly across the stream by measuring width, depth, and velocity. The measurements of depth are made with sounding-pole or sounding-line at ten or twenty points (or more on a large river) at equal distances along the line. The area of the cross-section of the stream at this line is thus closely determined. The velocity is of course different at different points in the width. Therefore in order to obtain a reasonably correct result the cross-section is divided into ten or more smaller sections (most conveniently of uniform width) by imaginary vertical lines, as shown in Figure 5, each of these being approximately a trapezoid (or rectangle, or at the margin, a triangle) whose area can be readily computed from the soundings. These small sections are taken narrow enough so that, if the velocity is different at the sides of a small section, the velocity at the middle point of the width of each may nevertheless be assumed to be a fair average. The velocity at the middle of each small section is then measured with the meter; when this velocity is multiplied by the area of the small section, the flow through that section is obtained; and then, by adding the flow of all the small sections together, the total flow of the stream is found.

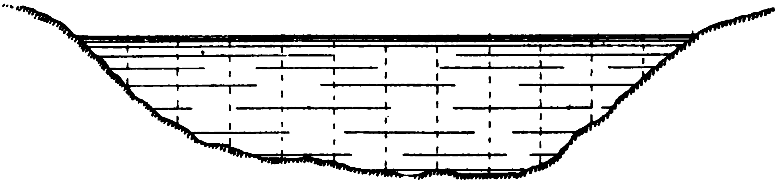

Fig. 5

Using the foot as unit of length and depth, the area of the cross-section will be given in square feet; using a speed of one foot per second as the unit of velocity of flow, the product of the cross-section and the velocity will give as a result the total number of cubic feet of water flowing by the observer each second, or the number of "second-feet", as the term is. For example, the statement that the flow of a stream is six second-feet does not indicate anything concerning the dimensions of its channel or the velocity of its current, but merely says that six cubic feet of water is discharged each second. The channel might be one foot wide and one foot deep with a current speed of six feet a second, or six feet wide and two feet deep with a current speed of one-half foot per second, or three feet wide and one foot deep with a current speed of two feet a second, or in any other ratio giving the same total product. The total flow will of course be the same, whether measured at a narrow, contracted point of large velocity or at a point where the current is wide, deep and sluggish.

This method is applicable to streams of any size from the largest rivers down, except very small ditches and brooks, and gives reasonably accurate results (with an error rarely as much as five per cent) if the stream is flowing in a good straight channel with even and unobstructed flow. It may be used from a bridge, from a small car running on a cable stretched across the river, from a boat, or in a small stream by wading, provided in these last cases that some means is used for holding the meter upstream from the observer, so that it will not be effected by the eddies caused by his feet or by the boat.

This method of measurement can be accurately employed on any artificial channel of appropriate form, such as a ditch or canal, if the speed is sufficient to turn the meter-wheel freely. If the channel is a timber flume or other form not liable to be changed, eroded or obstructed, a careful determination can be made once for all of the quantities of water flowing for various depths in the flume. In large irrigation canals it is a frequent custom to install rating flumes, timber-lined sections of a few rods in length; the side of such a flume is marked at each possible height of water surface with a number indicating the quantity of water flowing when the water rises to that height in the flume. It is then an easy matter for the ditch-rider or gate-tender to keep a continuous daily record of the total flow.

In a natural channel, if there are no dams or other obstructions for a considerable distance below the point of measurement and if other conditions are suitable, it will be found that the same amount of water flowing causes always almost the same height of water-surface in the channel, so that, after a series of such measurements of second-feet discharge at different stages of water, a rating-table can be prepared showing with fair precision (say within five per cent) the probable flow for any height of water. It is such representative points that the United States Geological Survey selects for the location of gauging stations. At these stations a vertical gauge rod painted in feet and fractions is placed in the water at a bridge pier or at the river margin, or other suitable device is installed, by means of which the height of the water surface may be accurately seen and recorded daily by a local observer. These observations are reported regularly to a district hydrographer who visits the stations from time to time to take soundings, velocity measurements, etc., for the purpose of finding the amount of flow corresponding to different heights of water on the gauge, and thus finally computing the total amount of water flowing down the stream in a year, and the greatest, least, and average flow for each month.

The United States Geological Survey has commenced in this state, chiefly within the past two years, since popular interest in irrigation has arisen here, a comprehensive system of stream measurements of this nature, gauging stations having been established on all the principal streams. At present one of the faculty of the University of North Dakota is the engineer in immediate charge of that branch of work for North Dakota and Minnesota.

The second, or weir-measurement, method affords still more accurate results when the conditions are favorable. A weir is a dam or small barrier with level crest over which the water flows. The depth of water on the crest evidently will be greater for a greater flow, and experiment has shown that the relation between them can be stated in definite figures if the weir is properly constructed. There are two forms of weir most frequently used, although special circumstances sometimes make other forms more convenient. The rectangular weir has vertical ends; the trapezoidal or Cippoletti weir, as shown in the illustrations (figures 6,

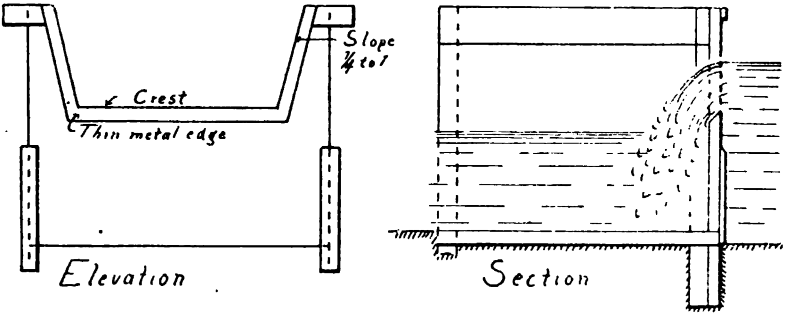

Fig. 6.

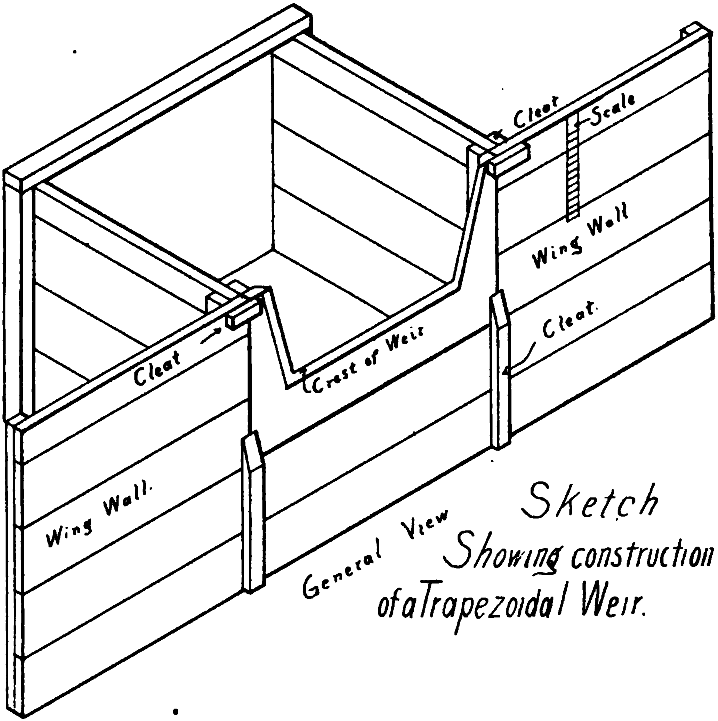

Fig. 7.

7, and 8) widens above the crest, each end sloping outward one inch in every four inches rise; the second pattern has the simpler formula for computation of flow.

In using the ordinary weir, it should be placed in the middle of the channel at right angles to the stream with its up-stream face in a vertical plane. The crest should be chamfered so as to slope downward on the lower side with an angle of not less than thirty degrees, leaving a sharp edge over which the water can leap freely without retardation by friction, or better still a stiff sheet of thin metal may be placed vertically to form the edge, and the ends should be chamfered likewise. The air thus

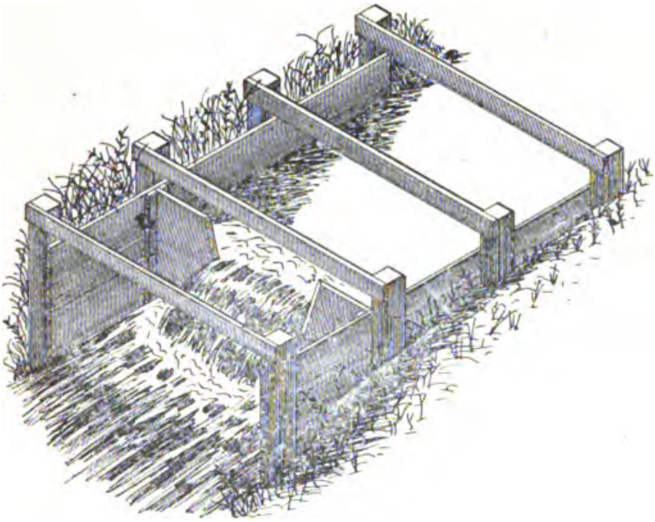

Fig. 8.

has free access under the falling water. In the pond caused by the weir, the water will be brought nearly to rest, and must approach the crest evenly and without cross-currents; this requires that the approaching channel should be straight and even and be at the weir more than twice the depth and at least three times the width of the jet passing over. The length of the weir opening should be three or four times the depth of the jet at the time of the greatest flow.

If the length of the crest of the weir, L, and the depth of water on (or rather, height of the water surface above) the crest, H, be measured in feet and decimals of a foot, the number, Q, of cubic feet of water per second flowing over a rectangular weir can be computed from this formula,

$$Q=3.33\ (L-0.2\,H)H\sqrt{H}$$

and over a Cippoletti weir

$$Q=3.37\ L\ H\ \sqrt{H}$$

The height above the crest of the weir of the level water-surface a few feet behind the weir may be readily found without level or other instrument thus: When the water is first filling the channel behind the weir, if a stake be driven in the water with attention that the top of the stake be exactly at the water surface at the instant that the water begins to flow over the crest, the subsequent depths of water over the top of this stake will be the required heights.

The formula for the flow is not a complicated one, and for a trapezoidal weir may be expressed in words, "multiply the square root of the depth above the crest by three and three-eighths times the product of the depth and the length of the crest, all being expressed in feet and decimals." But tables are prepared for all the standard sizes of weirs, and may be prepared for any with a few hours work, that give at a glance the amount of flow for each depth of water.

Convenient dimensions for weirs according to the expected amount of flow are given in this table:

For a discharge less than two-thirds second-foot make crest of weir one foot long.

For a discharge between two-thirds and two second-feet make crest of weir one and one-half feet long.

For a discharge between two and four second-feet make crest of weir two feet long.

For a discharge between four and ten second-feet make crest of weir three feet long.

For a discharge between ten and twenty second-feet make crest of weir four feet long.

For a discharge between twenty and forty second-feet make crest of weir five feet long.

Weirs are advantageous for use in canals and ditches where-ever sufficient fall can be afforded so that the water leaps freely over the crest without interference from backwater. They are often placed permanently in such cases, for variation in the amount of water flowing in a canal while in use is not great, hence the weir may be small enough to measure accurately the minimum flow, and yet be able to carry the greatest usual flow. In a natural stream, and especially in small streams, the seasonal variations are likely to be greater, and therefore any particular weir will be available for use only at certain stages; while on large streams the cost of constructing a weir would be disproportionately great. Sometimes there are water-power dams on such streams that have level crests and are otherwise so constructed as to permit such measurements; for, although they are not usually sharp-crested as required above, there are suitable formulas, similar to the preceding, giving the flow over wide-crested weirs and other forms.

In a small stream the summer low water flow may be determined without difficulty by making a weir of a few planks and placing it in the top of a small temporary dam of stones and turf, but this will of course be destroyed by the first flood.

One of the earliest units of water measurement was the "miner's inch," a unit of simple application which was measured in a similar fashion. According to Colorado statute, a miner's inch is defined as the quantity of water delivered through an inch-square orifice, under a five inch pressure measured from the top of the orifice to the surface of the water, in a box set in the banks of the ditch. It would evidently be inconvenient to measure large quantities of water by this unit, nor is it an accurate and definite unit, for a change in the shape of the orifice will change much the amount of water delivered, therefore its use is being abandoned. It is variously defined in different states, but a statement now accepted in many regions is the ratio that one second-foot equals fifty miner's inches.

The float-measurement method, though not giving accurate results, is quite simple and is fairly good if there is no strong wind or other such disturbing factor, and if on the stream a suitable straight portion with smooth, even current can be found. By stretching cords or wires across or by setting range poles on the opposite shores, two parallel lines are marked perpendicularly across the stream so as to include a convenient portion of the channel from ten feet to five hundred feet long according to the size and character of the stream, speed of current, etc. The width is measured and soundings with line or rod are made at numerous points across the width so as to give the average depth and therefore the area of the cross-section. This should be done under each of the parallel lines, and also if the stretch between them is long at one or two lines intermediate between them. Floats of some sort are then thrown singly into the stream above the upper line, the time each passes the upper line precisely noted, and the time it passes the lower line. If the total distance between the lines (in feet) be now divided by the time in seconds occupied by each float in passing down that distance its velocity in feet per second is found.

The average velocity of the stream may be assumed to be from four-fifths to eleven-twelfths of the surface velocity, according to wind, character of channel, etc. For a large stream in an unobstructed channel with smooth mud or sand bottom, the average velocity is likely to be nearly nine-tenths of the surface velocity; but in a smaller stream with bottom of pebbles and small stones the average may not be more than five-sixths the surface velocity. Also a wind if down stream of course increases the surface velocity and if upstream decreases it.

The floats may be sticks and chips or anything else convenient, but must be as nearly submerged as possible, especially if the current is sluggish, to avoid catching the wind. Bottles tightly corked after being partially filled with water so as to be almost submerged are good in a river.

Other more elaborate floats, such as rods weighted so as to float vertically, extending nearly to the bottom of the channel, or double floats with a weighted vane in the lower portion of the stream hanging by a cord from the visible float at the surface are sometimes employed, with the intention of obtaining directly the average velocity; but their use is as troublesome as the employment of the more accurate current-meter.

On a large stream this work requires several persons, but one person alone can obtain after a little practice fairly good results on a small stream, especially if a cheap stop-watch is used for timing. The computation of a float measurement may be made by several methods. Most simply, after floats have been timed along every part of the width the velocity given by each float may be found, their average taken as the average velocity of the stream, and the cross-section of the stream multiplied by the average velocity to obtain the flow. If the stream is of considerably different depth in different portions of the width, quite large errors may enter unless more floats are taken in the deeper portions, somewhat in proportion to the depths. Note that the velocities should be averaged, not the times of floating down, in order to avoid giving undue weight to any float that happened to be delayed in the edge of the stream. This method is fairly satisfactory for a small brook, and is illustrated by this example:

Float measurement of Little Muddy river twenty-five miles north of Williston, September 14, 1904:

Length taken for run of floats, 20 feet.

Average width, 5 feet 6 inches.

Depths (taken at equal intervals on four lines across stream):

1, 2, 2, 3, 2 inches.
1, 1, 2, 2, 1 inches.
1, 2, 3, 2, 1 inches.
2, 2, 3, 1, 1 inches.

Therefore the average depth is 1.75 inches or 0.146 feet.

Depth multiplied by width gives area of cross-section, 0.80 square feet.

Number of seconds taken by floats in running 20 feet: 13, 11, 9, 10, 8, 10, 13, 12, 12, 22, 8, 10, 9, 11, 9 seconds.

Length of run divided by time gives speed of each float in feet per second: 1.54, 1.82, 2.22, 2.00, 2.50, 2.00, 1.54, 1.67, 1.67, 0.91, 2.50, 2.00, 2.22, 1.82, 2.22. Average surface velocity, 1.98.

Slight wind downstream; if total average velocity is taken as four-fifths of surface velocity, four-fifths of 1.98 is 1.58.

Area of cross-section multiplied by velocity gives total flow; 0.80 multiplied by 1.58; total flow, 1.26 cubic feet per second.

A better method is to imagine the stream divided (as detailed under the description of the current-meter method) into sections of narrower width, say one foot, two feet, five feet or ten feet, and to run several floats in each small section, from the velocity of which with the measurements of depth the amount of flow through each small portion of the whole cross-section may be separately computed, and the total flow obtained by adding these.

This method is illustrated by the following example:

Float measurement of Knife River, ten miles above mouth, August 26, 1904—whole width, thirty-two feet, divided into sections four feet wide. Depths taken and floats run through middle of each section. Length of run, fifty feet.

Distance from right bank—feet	Depth at upper line—feet	Depth at lower line—feet	Average depth—feet	Width of section—feet	Area of each section—square feet	Average time of floats—seconds	Surface velocity—feet per second	Discharge of each section—cubic feet per second
2	0.4	0.6	0.5	4	2.0	193	0.26	0.52
6	0.9	0.9	0.9	4	3.6	108	0.46	1.66
10	1.3	1.1	1.2	4	4.8	46	1.09	5.23
14	1.6	1.4	1.5	4	6.0	39	1.28	7.68
18	1.4	1.2	1.3	4	5.2	34	1.47	7.61
22	1.2	1.2	1.2	4	4.8	41	1.22	5.86
26	1.0	1.2	1.1	4	4.4	62	0.81	3.56
30	0.9	0.9	0.9	4	3.6	235	0.21	0.76
Total discharge..								32.91

No wind. If average velocity is taken as seven-eighths of surface velocity, seven-eighths of 32.91 is the total flow, 28.80 cubic feet per second.

(Note. The distances, depths, and times are found in the measurement, and the other columns filled in the computation. Area of section multiplied by velocity equals discharge).

Several units for water-measurement are frequent. The one used above is the "second-foot" which means a flow of one cubic foot each second, and is the most convenient unit. Gallons per minute or per day are often used, especially in connection with city water supply. One second-foot is equal to about 7½ gallons per second, 450 gallons per minute, or 650,000 gallons per day, which affords much larger and more impressive figures for presentation to the tax-payers who are meeting the expenses of the pumping plant. The "miner's inch," or merely "inch," is another unit, of rather indefinite value as described above. The most frequent unit for measurement of water stored in reservoirs is the acre-foot, a quantity of water sufficient to cover one acre a foot deep. A flow of one second-foot will amount to almost two acre-feet per day.

If it is prospective use for irrigation that gives value to the stream, after a measurement of the amount of flowing water has been made the next question that arises is "How much land will this stream irrigate?" This leads to a discussion of the duty of water. The duty of water, as the ratio between the number of units of land and of water properly to be applied to it is called, is not everywhere the same, but depends upon the climate, upon the character of the soil tilled, and upon the nature of the crops cultivated; experience will bring more definite knowledge concerning the needs of the land in this state. But as a conservative estimate the general statement may be made that eighty acres may be irrigated with one second-foot of water. In most of the western states some such figure is set as the legal duty of water, that is to say as the amount of water that the owner of any particular tract of land is not entitled to exceed in his claims.

Another phrase which is especially convenient in deciding how much land a storage tank or reservoir full of water will irrigate is the the statement, as yet tentatively made, that in North Dakota two acre-feet of irrigation-water to each acre of land per year should be sufficient for most crops, i. e., enough water to cover the land two feet deep if none of it were soaking in or running off. It may be noted that a continuous flow of one cubic foot per second would cover eighty acres two feet deep in about eighty days; so that, assuming an irrigating season of eighty days, the phrases above would have the same value.

Whatever quantity of water is assumed as needed, be it a flow continuously during the irrigation season of one second-foot for each eighty acres or an amount sufficient to cover the land two feet deep or more, or less, an approximate knowledge of the amount of water available for use is the prime essential, and it will be found that with a very little practice this can be at least roughly obtained by some of these methods. A few such measurements at high water, medium stages and low water on any stream will prove very helpful if its use for irrigation or any other purpose is contemplated. Advice or assistance in any difficulties arising in such measurements will be freely offered in reply to any letter of inquiry sent either to the State Irrigation Engineer or to the State Geological Survey, at the postoffice, University, N. D.

THE RUN-OFF OF THE STREAMS IN NORTH DAKOTA

An interesting problem in local geology or physical geography is the relation between the rainfall of any region and the run-off of its streams. This is not a problem that can be solved from studies in a single locality and a constant ratio found once for all between the depth of the rainfall and the quantity of water flowing away in the streams; the ratio varies in different regions, in different seasons, and in years of unusually large or small rainfall. Even in a single state there are large variations if regions of as great dissimilarity in topography as the extremes of North Dakota are included.

A study of the records of the stream-gauging stations that the U. S. Geological Survey maintains in the state, which records are briefly summarized in the following pages, and a study of the diagrams for graphic illustration, bring to view many interesting facts concerning this problem, a few of which may appropriately be noted here.

"The waters of the earth are taken up by the process which we call evaporation and formed into clouds, to be again precipitated to earth in the form of rain or snow. Of the water which falls upon the basin of a stream, a portion is evaporated directly by the sun; another large portion is taken up by plant growth and mostly transpired in vapor; still another portion, large in winter but very small in summer, finds its way over the surface directly into the stream, forming surface or flood flows; finally, another part sinks into the ground, to replenish the great reservoir from which plants are fed and stream flows maintained during the periods of slight rainfall, for the rainfall is frequently, for months together, much less than the combined demands of evaporation, plant growth, and stream flow. These demands are inexorable, and it is the ground storage which is called upon to supply them when rain fails to do so.

All of these ways of disposing of the rain which falls upon the earth may be classed as either evaporation or stream flow. Evaporation we make to include direct evaporation from the surface of the earth, or from water surfaces, and also the water taken up by vegetation, most of which is transpired as vapor, but a portion of which is taken permanently into the organisms of the plants. Stream flow includes the water which passes directly over the surface to the stream, and also that which is temporarily absorbed by the earth to be slowly discharged into the streams.*"

If the rainfall is measured at well distributed points, so that the average rainfall over the basin of any stream is known, and if the records of the quantity flowing down the stream are kept, the ratio between the evaporation and the stream flow, or rather between the total rainfall and the portion that escapes evaporation and runs off, is at once known for that season.

North Dakota falls within three principal drainage areas as follows:

The Hudson Bay drainage area. Hudson Bay receives the waters from the Red river and its tributaries, the principal of which are the Mouse, the Pembina, and the Sheyenne, and (from Minnesota) the Red Lake. This includes the eastern side of the state and portions of the northwestern and central regions.

The Devils Lake drainage area. This interior basin which has no outlet receives the small streams from the middle northern section of the state.

The Missouri River drainage area includes, roughly speaking, that half of the state cut off by a diagonal from the southeast to northwest corners. The principal tributaries of the Missouri are, on the east side the James, on the west side the Little Missouri, Knife, Heart, and Cannon Ball.

The Red river is the largest stream in the state except the Missouri. The fall of its main valley is small, only about one foot per mile. It is the boundary between North Dakota and Minnesota and during most of the year receives its main supply from the Minnesota side, where the rainfall is somewhat greater and therefore the surplus running off unevaporated is much greater and where the forests protect the water upon the surface and in the soil from the wind and from evaporation, so that the residue running off is greater; they also hold back the water of the spring and of the storms, giving a more constant perennial flow.

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*U. S. Geological Survey, Water Supply Paper, No. 80, by Geo. W. Rafter.

The Red river itself rises in Otter Tail and other lakes in Minnesota and curving southwest reaches the North Dakota boundary at Wahpeton. At Fargo the Sheyenne enters it from the west, and although the area which the Sheyenne has drained is slightly greater than that of the Red, its average flow is scarcely more than half as great.

The Red Lake river comes direct from the lakes and woods in northern Minnesota, entering the Red at Grand Forks; though the area it drains is less than three-tenths the drainage area of the Red above Grand Forks, (and is not as large as that of the Sheyenne) its flow is nearly as great as that of the Red river, and in summer is much greater, so that from thirty to sixty per cent of the water below Grand Forks comes from the Red Lake river. Its flow is from ten to twenty times that of the Sheyenne, except for a brief time in the spring.

The Red river is peculiar among the streams of the United States in that it flows north, and before the ice has broken on its lower reaches the spring thaws are in force in the upper valley and all the coulees and streams bank full. Hence the ice carried down from the upper part does not find clear passage and jams and high water are likely

The high water of 1897 is the highest recorded, coming at Grand Forks within a foot of the level of the pavements of the city streets in most of the city. In 1904 so extreme a height was not reached by almost ten feet, but the duration of high water was much longer, the water being within six feet of its highest mark this season for twenty-five days.

All the streams in this area are usually deliberate in their actions on account of their small fall; there are no sudden changes in height nor in the streams fed from the forests of Minnesota are there great extremes in flow. The difference between maximum and minimum is seen to be comparatively small for any month except sometimes in the early spring. The Sheyenne has a fall of only about three feet per mile of valley. The Red river, with its much less fall would degenerate into a mere slough, choked with vegetation, were it not for the large amount of water that it carries. This is the case with the James, whose fall is about two feet per mile, and in a dry season its summer flow is only ten or twenty second-feet or less, insufficient to keep its channel clear.

The Mouse river, whose fall for the sixty miles of valley between Minot and Towner (through which the river meanders so as perhaps to double the total distance) is only eighty feet, is also extremely sluggish. Thus even in the unprecedented flood of April, 1904, when the stream was out of its banks and covering the whole valley bottom, it flowed away so slowly that for thirty days at Minot it was within three feet of its highest mark.

The Little Muddy, a stream flowing into the Missouri from the north at Williston, exhibits similar features, though its fall is greater.

On the other hand, the streams in the southwestern portion of the state west of the Missouri, such as the Little Missouri, Cannon Ball, Knife, and Heart, have a larger fall, from three to six feet per mile of valley in the lower portions and much more near the headwaters. This is why they have been able to erode their valleys rapidly and deeply so that cut-banks and bad lands abound. Nor are there forests anywhere in their drainage basins to retard the run-off; in the summer after a rainstorm the water runs violently down the stream, causing a sudden flood, and the stream as quickly returns to its former low stage.

This is markedly shown in the run-off tables of these streams and even more clearly in the diagrams by the great difference between maximum and minimum flow. One of these streams may run ten, twenty, or even 100 times as much water tomorrow as today.

No records of the Missouri river in this state have yet been maintained long enongh for publication. This river from the point of view of physiography is a complex problem. Part of its volume comes from the draws, coulees and rivers of the North Dakota prairies with their violent floods at the time of the spring thaw; this causes the spring rise, which then sometimes rises to an abnormal and disproportionate height as a result of ice jams and gorges. Later in the season the snows in the mountain ranges at the headwaters of the Missouri melt, keeping the river at a high-water stage in early summer.

Another point to be noted is that a single year's record gives a very inadequate idea of the future behavior of a stream. The run-off is ultimately (though some of it is delayed by soaking into the earth and thence out from springs) the residual left from a variable rainfall after plant absorption, evaporation, and all losses have taken place. For the streams of southwestern North Dakota the total amount thus unused and running off may not amount to as much as *one inch* over the whole drainage basin in the course of a year. A very slight difference in the amount or in the seasonal distribution of the rainfall may cause a difference in this residual (the run-off) that is large in comparison with the total amount, and this difference cannot be easily predicted.

A thorough understanding of the behavior of even a single one of our many rivers can not be obtained without a thorough study of its whole drainage area, including the topography, the grades, the forests or vegetation, the nature and condition of the soil and surface, and the geological structure, followed by a comparison between the region's rainfall and run-off records for many years. But the pages above are a preliminary contribution to the study of the subject.

Many illustrations of the apparent inconsistencies in the behavior of the different streams may be seen in the tables following. For example, in the summer and early fall months of 1904 the average flow of the Red River at Fargo was slightly more than double its average flow for the same month in 1903; the Sheyenne for those months had double the flow of the same months in 1903; the Red Lake River, one and one-halt times as much; the Pembina, more than ten times as much; but the Mouse River averaged less flow than for the same months of 1903; the Knife River less, and the little Missouri less than one-third. These apparent inconsistencies could be explained, at least in part, if space permitted here, but at first glance are surprising.

TABLES SHOWING DISCHARGE IN SECOND-FEET OF NORTH DAKOTA RIVERS

These tables were prepared from a series of daily observations, made under the direction of the U. S. Geological Survey, at each point, and give with reasonable accuracy the quantity of water flowing by the station, maximum flow, minimum flow, and mean

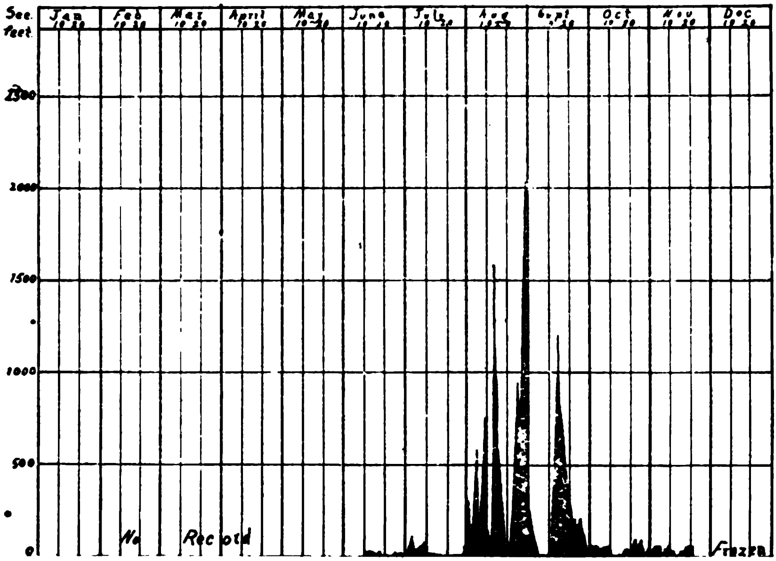

Fig. 1. Discharge of Cannon Ball river at Stevenson, 1903

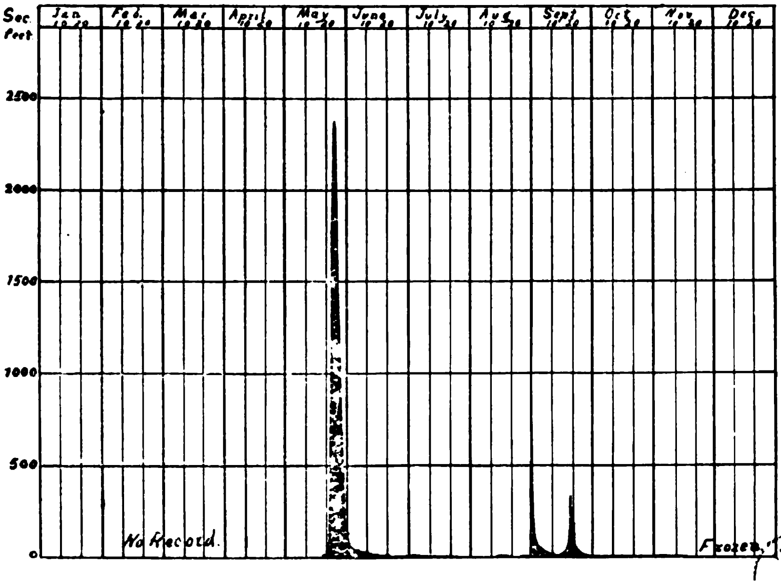

Fig. 2. Discharge of Heart river near Richardton, 1903

or average flow being given. The term "second-feet" is an abbreviation for "cubic feet per second"; it is the number of cubic feet of water flowing by the gauging-station each second. From the number of second-feet of mean discharge by multiplying by the number of seconds in a day or in a month, the total number of cubic feet of water passing down the river in a day or in a month is of course readily found.

RED RIVER AT GRAND FORKS, N. D.

BELOW MOUTH OF RED LAKE RIVER.

(Drainage area about 25,800 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
April	18,800	5,900	10,700
May	7,140	4,270	5,390
June	5,870	1,940	3,340
July	2,100	1,060	1,440
August	1,270	870	1,050
September	2,660	1,180	1,890
October	3,940	1,400	2.990
November	......	......	2,200
1904			
April	32,900	2,900	22,200
May	30,200	6,390	14,000
June	6,750	5,070	6,000
July	6,270	2,400	3,920
August	2,280	1,320	1,760
September	1,910	1,460	1,610
October	2,140	1,580	1,850

RED LAKE RIVER AT CROOKSTON, MINN.

(Drainage area about 5,500 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
June	2,940	1,060	1,820
July	1,350	810	1,000
August	1,110	450	669
September	2,390	840	1,390
October	2.430	730	1,930
November	1,810	430	1,270
1904			
April 3-30	13,600	2,900	7,810
May	7,620	3,700	4,450
June	3.780	2,940	3,340
July	2,640	1,090	1,820
August	1,290	710	930
September	1,450	760	1,020
October	1,180	760	1,030

PEMBINA RIVER AT NECHE, N. D.

ABOUT 15 MILES ABOVE MOUTH.

(Drainage area about 2,800 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
May	230	167	209
June	198	110	144
July	110	35	60
August	......	......	33*
September	......	......	33*
October	45	32	40
1904			
April 4-30	3 580	30	1,630
May	3,870	1,340	2,640
June	2.530	929	1,620
July	2,690	376	837
August	420	310	383
September	310	225	294
October	266	206	211

*Estimated.

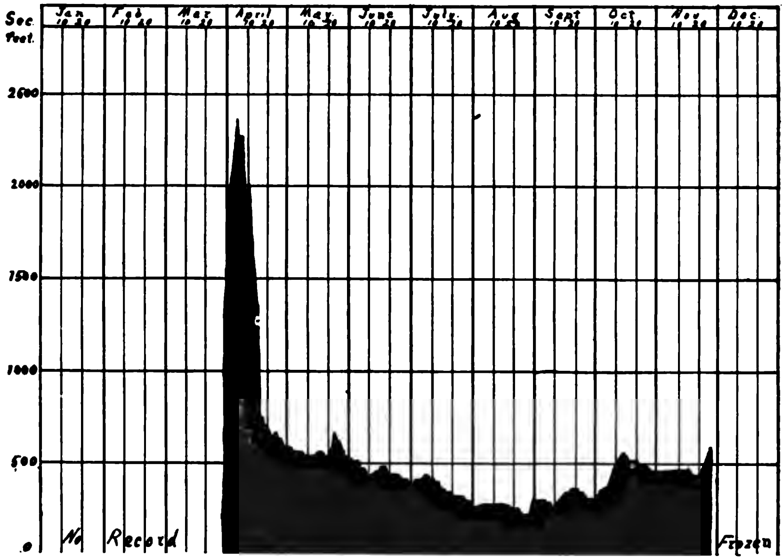

Fig. 1. Discharge of Red River of the North at Fargo, 1903

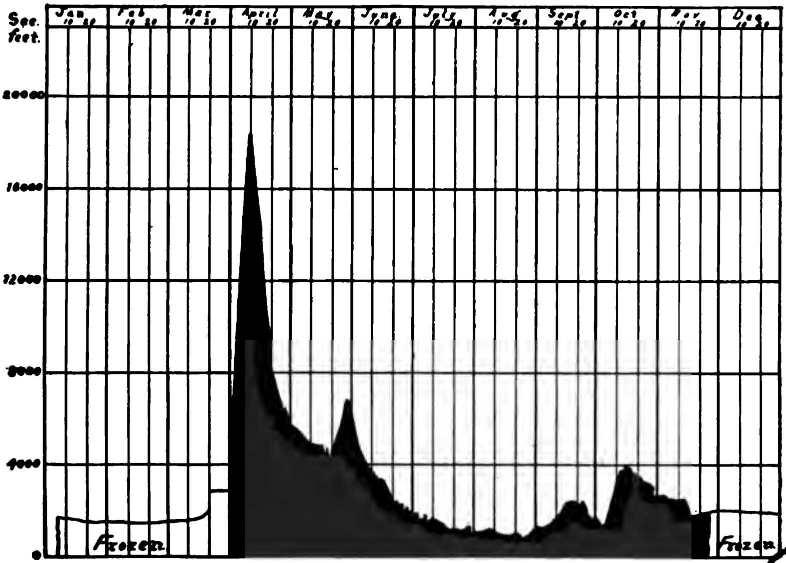

Fig. 2. Discharge of Red River of the North at Grand Forks, 1903

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RED RIVER AT FARGO, N. D.

(Drainage area about 6,000 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
April	2,450	565	1,280
May	645	539	577
June	539	392	460
July	439	283	363
August	325	225	268
September	369	263	317
October	565	325	487
November	......	......	474
1904			
April	5,550	1,020	2,780
May	1,650	878	1,050
June	2,820	822	1,270
July	2,350	636	1,100
August	636	378	502
September	512	378	450
October	512	444	483

SHEYENNE RIVER AT FARGO, N. D.

ABOUT 15 MILES ABOVE MOUTH.

(Drainage area about 5,400 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
April 8-30	1,570	410	1,000
May	1,110	158	369
June	302	84	166
July	146	53	80
August	67	20	46
September	113	53	81
October	124	60	99
November 1-14	......	......	100
1904			
April	1,950	810	1,430
May	1,950	368	1,045
June	615	296	418
July	296	139	216
August	130	36	88
September	105	32	83
October	139	80	93

MOUSE RIVER AT MINOT, NORTH DAKOTA.

(Drainage area, 8,400 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
May 5-31	347	191	251
June	599	191	324
July	401	178	271
August	248	165	186
September	1,136*	178	696
October	509	205	293
1904			
April 3-30	12,000†	438	5,200
May	7,600	2,080	4,850
June	1,960	402	804
July	402	165	268
August	165	114	128
September	114	60	79
October	87	60	66

*Violent snowstorm early in September.

†Estimated. River out of its banks; highest flood for twenty years.

LITTLE MUDDY RIVER AT WILLISTON, NORTH DAKOTA.

(Drainage area, about 800 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1904			
April 3-30	3,000*	750	1,300
May	700	23	164
June	65	16	24
July	16	10	12
August	10	6	8
September	10	6	9
October	10	6	10

*Estimated. Highest flood for years.

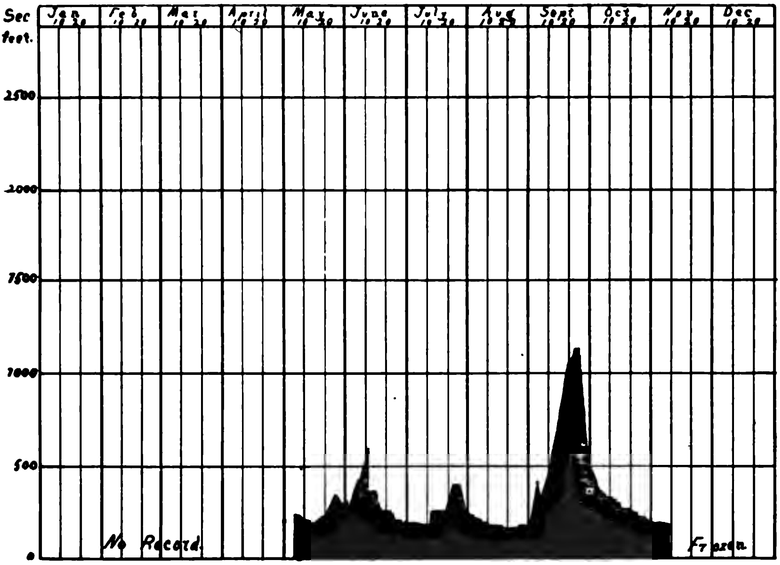

Fig. 1. Discharge of Mouse river at Minot, 1903

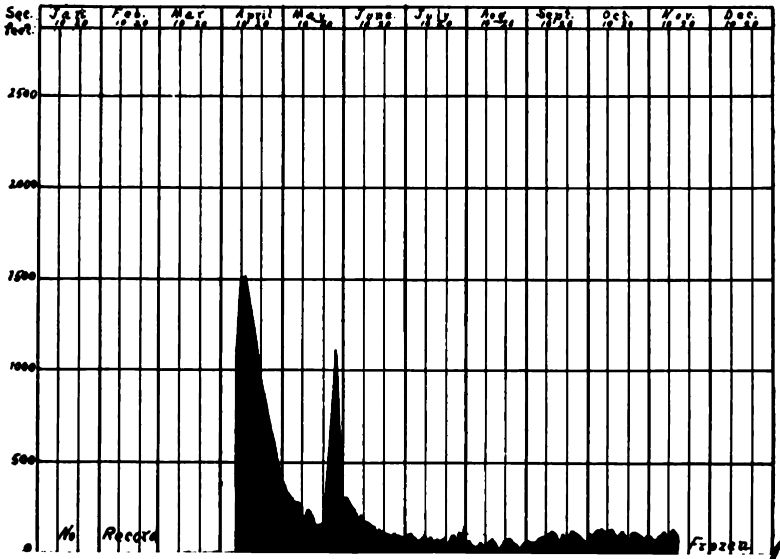

Fig. 2. Discharge of Sheyenne river at Haggart, 1903

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CANNON BALL RIVER AT STEVENSON, NORTH DAKOTA,

ABOUT THIRTY MILES ABOVE MOUTH

(Drainage area, about 3,650 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
June 10-30	38	7	18
July	116	3	24
August	2,040*	17	434
September	1,270	7	268
October	53	11	38
November 1-21	53	11	40
1904			
April	3,720	195	1,246
May	195	33	95
June	2,040	47	618
July	107	4	31
August	22	0	3
September	8	0	2
October	107	1	15

*Unusually heavy August rains.

LITTLE MISSOURI RIVER AT MEDORA, NORTH DAKOTA,

ABOUT 140 MILES ABOVE MOUTH.

(Drainage area, about 6,600 square miles.)

Month	Discharge in second-feet		
	Max.	Min.	Mean
1903			
May 12-31	2,880	39	952
June	830	54	237
July	3,900	122	1,083
August	6,100*	500	2,295
September	5,550	176	1,242
October	147	43	68
November 1-14	101	61	76
1904			
March 13-31	2,480	452	986
April	2,480	64	802
May	400	110	180
June	6,090	110	1,195
July	352	27	103
August	27	5	9
September	307	4	80

*Unusually heavy August rains.

HEART RIVER NEAR RICHARDTON, N. D.

ABOUT 100 MILES ABOVE MOUTH.

(Drainage area, 1,270 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
May 18-31	2,500	13	611
June	118	5	22
July	13	0	4
August	530	0	18
September	336	8	67
October	13	8	8
November 1-18	......	.....	8
1904			
April	3,500	151	1,050
May	169	19	56
June	461	13	98
July	13	0	6
August	2	0	1
September	1	0	1
October	4	0	2

KNIFE RIVER AT BRONCHO, N. D.

ABOUT FORTY MILES ABOVE MOUTH.

(Drainage area, 1,250 square miles.)

Month	Discharge in second-feet.		
	Max.	Min.	Mean
1903			
June	64	24	30
July	840	16	60
August	311	16	46
September	217	13	62
October	13	11	12
November 1-14	13	9	11
1904			
April	3,400	111	1,050
May	330	39	97
June	350	26	74
July	39	5	12
August	5	3	4
September	4	3	3
October	14	3	7

A continuous record of the height of the Red river at Grand Forks has been kept since the summer of 1895. By the kindness of Captain John F. Hayes some facts from the record are given here.

Referred to the gauge now maintained by the U. S. Geological Survey, whose zero is 780 feet above sea level, the heights of water at highest and lowest each season with dates, were these:

Year	Highest Water	Lowest Water
1895		3.8 feet September 26
1896	32.0 feet May 30	5.6 feet October 8
1897	50.2 feet April 10*	6.9 feet November 13
1898	15.0 feet April 14	5.4 feet November 13
1899	20.9 feet April 17	5.7 feet November 11
1900	16.5 feet October 13†	3.4 feet July 1
1901	26.2 feet April 6	6.2 feet September 24
1902	26.0 feet March 30	5.9 feet October 23
1903	27.9 feet April 11	5.0 feet August 24
1994	40.6 feet April 27	6.0 feet August 30

*Caused by unusually heavy snow the previous winter.

†Heavy rains in the early fall.

The dates on which navigation opened and on which the river froze over at Grand Forks, and the approximate average height of water for each season as a whole (from opening to closing) were these:

1895; navigation opened about April 16; closed November 1.

1896; navigation opened about April 18; closed November 13; average heighth about ten feet.

1897; navigation opened about April 10; closed November 15; average height about fourteen feet.

1898; navigation opened about April 15; closed November 10; average height about seven feet.

1899; navigation opened about April 19; closed December 3; average height about ten feet.

1900; navigation opened about April 14; closed November 15; average height about twelve feet.

1901; navigation opened about April 9; closed November 6; average height about eleven feet.

1902; navigation opened about April 7; closed November 12; average height about eleven feet.

1903; navigation opened about April 13; closed November 14; average height about ten feet.

1904; navigation opened about April 18; closed November 28; average height about twelve feet.

The zero of the gauge on the Red river at Fargo is 861 feet above sea level, and since its establishment the records of highest and lowest water and approximate average during open season are as follows:

1901, highest, —— lowest, 6.8 feet November 6; average height about 8 feet.

1902, highest, 10.3 March 18; lowest 6.7 November 13; average height about 8 feet.

1903, highest, 13.9 April 6; lowest 7.0 August 28; average height about 8 feet.

1904, highest, 21.3 April 20; lowest 7.7 September 1; average height about 10 feet.

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